Study on the Effectiveness of Modeling and Simulation in the Weapon System Acquisition Process

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Final Report

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Forward

In August 1995, I commissioned a one year study with the objective of assessing the effectiveness of the use of modeling and simulation (M&S) in the acquisition process. In particular, I was looking for the metrics by which the Department of Defense could ascertain the value—if any—that was returned on its investment in M&S in terms of the reduction in time, resources, and risk in weapons systems development and fielding and in terms of increase in the military utility of those systems. I also tasked the study team while gathering information to support the assessment to note technical and other challenges to realizing the postulated benefits and to report on specific M&S tools and processes being used to facilitate the acquisition of systems in the DoD and industry.

This report, which documents the results of that study, provides tangible, quantitative indicators that the use of M&S can provide substantial benefit measured in time, cost, productivity, and system quality and performance. The evidence is consistent and pervasive, across both DoD and industry. I personally was impressed that the most significant return on investment was realized when M&S was used as an integrator of functions within the acquisition process, i.e., integrating design and manufacturing or linking requirements more closely to test. This leads me to believe that its real value lies as an enabler of Integrated Product and Process Development (IPPD).

The research also sheds light on the work that remains to be accomplished if the Department is to truly realize the full potential of M&S in providing enhanced capability to its warfighters. Technical, managerial, and cultural challenges remain to be addressed. The study team has made some recommendations. The acquisition community may draw additional conclusions from the study on actions that should be taken.

I am therefore providing this report on the "Effectiveness of Modeling and Simulation in the Weapon System Acquisition Process" to the defense acquisition community for the multiple purposes of alerting acquisition professionals to the potential of M&S technologies; of establishing a broader basis for supporting investment and employment decisions on M&S in the Department; and of embarking on a strategy to more fully achieve the vision of Simulation Based Acquisition.

Dr. Patricia Sanders
Deputy Director, Test, Systems
Engineering and Evaluation

ACKNOWLEDGMENTS

This study is a result of the efforts of personnel on the Army, Air Force, and Navy staffs and the many supporting personnel in the research and development and test and evaluation communities. Their insights and willingness to share their expertise provided the Study Team with enough background to investigate the acquisition programs that would generate information necessary to conduct this study.

The active advice and counsel from several individuals are significant to note: Mr. Walter Hollis, Deputy Under Secretary of the Army (Operations Research); Mr. Mike Roberts, Acquisition Reform Office for the Assistant Secretary of the Navy (Research, Development, and Acquisition), and Major Bryan Ishihara, Air Force Test and Evaluation. These three lent their support in opening doors and taking a personal interest in the ongoing collection of information throughout the course of the study.

The Study Team would like to recognize, with gratefulness, the courtesy and effort extended by the many Program Manager and Program Executive Offices from which we gathered information. In many cases, they went beyond the expected effort to host yet another information gathering team, and provided us with more information than could be included in this study report.

The study would not be complete without consideration of the implications of Modeling and Simulation use in Industry, both defense and commercial. The team appreciates the forthright information from several companies including: Sikorsky Helicopter; General Motors-Truck and Bus Division; Deneb Robotics, Inc.; Lockheed Martin; Ford Motor Company; and General Dynamics, Electric Boat Division. We appreciate their time and candor in providing examples for use in this study.

The Study Team would also like to recognize those who reviewed the final report and provided valuable critiques: Mr. Gil Brauch, Logistics Management Institute; Dr. John Foulkes, Army Test and Evaluation Management Agency; Mr. Dan Billingsley, Headquarters, Naval Sea Systems Command; Ms. Mahnaz Dean, Office of the Assistant Secretary of the Navy (Research, Development, and Acquisition); Major Bryan Ishihara, Air Force Test and Evaluation; and Mr. Phil Rosen, SAIC at the National Automotive Center.

Finally, the Team would like to thank Dr. Patricia Sanders, the Study Sponsor, who managed to keep us focused on the task at hand without tempering our enthusiasm for investigation. We are grateful to her for the opportunity to make this contribution.

Annie Patenaude
Principal Investigator

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I. EXECUTIVE SUMMARY

A. Background

Dr. Patricia Sanders, Deputy Director, Test Facilities and Resources, Office of the Director, Test, Systems Engineering and Evaluation (DTSE&E), tasked Science Applications International Corporation (SAIC) to conduct a study to assess the effectiveness of using modeling and simulation (M&S) in the weapon system acquisition process. The study team was to investigate metrics that are being used to evaluate M&S effectiveness; specific tools that are being used by government and industry to facilitate the design, development, test, manufacture, and support of weapon systems in an Integrated Product and Process Development (IPPD) environment; the associated benefits of using M&S in the acquisition environment; and technical challenges that preclude the seamless use of M&S in the acquisition process.

In order to obtain focused information on the issues, the study team visited knowledgeable persons in both Government and Industry. The focus of these visits intentionally excluded training and requirements definition. Though both areas benefit from the use of modeling and simulation, studying them would have broadened the scope of the study and limited the time and resources spent on other areas from which data were gathered.

This study addresses the events that pushed the use of M&S in acquisition and what the resulting efforts were in the DoD community. It also addresses where this is taking acquisition in terms of opportunities and general trends. A brief synopsis of the study methodology is presented, along with examples of key visits and efforts noted. Some of the research results are cited; both in terms of some of the benefits and in many of the challenges facing the DoD acquisition community today. Finally, findings and recommendations are presented along with summary observations.

The environment was key to using M&S in acquisition processes: M&S tools and processes were more powerful and less expensive due to advances in technology; and declining resources made it essential that better ways be found to field weapon systems. The result was that many weapon system acquisition programs began using M&S tools in pieces of their acquisition process. At the same time, research and development centers and test and evaluation facilities were developing M&S tools and processes for both program specific and general use. It should be noted that these were independent efforts not coordinated by any specific agency or office.

Recent changes in guidance from both OSD and the Services have begun to influence the effort to manage the integration of M&S efforts both within the programs and across each Service. OSD guidance on using Integrated Product Teams is impacting the sharing of information on models and data within programs. Each of the Services have increased their emphasis on the use of M&S in acquisition and are modifying the way they do business.

B. Vision

Although it is not clear where these efforts will lead the acquisition community, it is evident that a significant change is underway and that the end result will be a new way of doing business. We will call this new approach to acquisition, "Simulation Based Acquisition," in order to differentiate it from the traditional approaches and to emphasize its reliance on the tools and processes made possible by advances in simulation technology. It is not presented here as a specific, definable concept, but rather as a term to characterize the general approach of significantly increased and innovative use of M&S tools and the processes which they enable; a more integrated approach to system development.

Simulation Based Acquisition is the process by which simulation is incorporated and integrated throughout the functions of the acquisition of a weapon system; from concept exploration, through prototyping and design, test and evaluation, fabrication and production, to deployment and finally operations and sustainment. Using M&S in acquisition is not a new idea. Simulation is already being successfully incorporated in each function in individual weapon systems acquisition programs in each of the Services. What is new in Simulation Based Acquisition is the integration of technologies across functions, phases, and programs.

C. Study Methodology

This report is the result of a one year study effort with extensive research in DoD and Industry. The investigation into M&S issues in acquisition was comprehensive but not exhaustive. The study team sought to provide examples and metrics of M&S effectiveness in simulation based design, virtual prototyping, computer aided engineering and manufacturing, and simulations used in testing, support, and system integration.

Visits were made to individuals on the Service Staffs, Research and Development Centers, Test and Evaluation agencies, Program Managers and Program Executive Offices, and some Industry activities (both defense and commercial). In addition to key individuals on the Army, Navy, and Air Staffs, the study team visited Ford Motor Company, Sikorsky Helicopter, General Motors-Truck and Bus Division, and researched other companies using simulation in an integrated manner in their design, development, and engineering and manufacturing processes.

Initial research gathered from DoD and Service staffs, as well as literature research, led the study team to believe that Simulation Based Acquisition would show payoffs in all areas of the acquisition process: in design and development, where three dimensional solid models would allow rapid evaluation of concept design and reduction of physical prototypes; in test, where data gathered from simulations could allow assessment of what would not be easily testable and could help avoid costly repetitions of shots; in manufacturing, to reduce cost/schedule risk and develop and validate 3-D manufacturing planning; in support and integration, to integrate maintenance and logistics requirements and evaluate new processes. These assumptions then provided a framework for further research effort.

D. Research Results

The study team found pervasive evidence of M&S being utilized efficiently in every Service, though not in the same way and not yet seamlessly throughout a program. Both Government and Industry are identifying and developing tools that bring added benefit to their program's development. Many examples of individual successes were found which were then used to identify metrics to validate the effective use of M&S.

Documented successes and experiences can be categorized into four areas of realized benefits; cost, schedule, productivity, and quality/performance. These categories are not mutually exclusive. Savings in productivity can also be classified as schedule benefits. The point was to identify benefits cited by activities and weapon system acquisition programs and find associated metrics. The benefits presented in this report are a fraction of those encountered but give a broad look at the types of examples of M&S being used effectively in acquisition.

Cost savings are especially difficult to quantify and reported cost savings are often illusionary. The cited benefits are more correctly classified as "cost avoidance" and are measures of significant additional work or results that were obtained using M&S tools which would have cost the reported "savings" if they had been obtained by more traditional methods. This study has been careful to differentiate between cost savings and cost avoidance and to clearly identify the latter category when reported. In some cases, the program itself would not be economically feasible without these improved methods which provide adequate risk reduction for an affordable cost.

One example of expected cost savings based on a six month side by side comparison is given by the Joint Strike Fighter Program Office. The study projected that the benefits of virtual manufacturing offer a potential savings of up to 3% of life cycle costs which could equate to $5 billion.

Two types of cost benefits are significant to note. The first is the effort and resources not used in programs that were terminated during concept exploration as a result of assessment using M&S tools. The other is programs, such as the Longbow Hellfire missile, that were able to find less expensive approaches using M&S, in this case to temper costly fly-to-buy testing. The Longbow Hellfire program invested in an anechoic chamber facility that enabled the program to cut back on the number of live missiles fired for lot verification of stockpiled munitions when compared to previous tactical missile programs. Without the use of M&S tools, the Hellfire missile would have been unaffordable in life cycle costs.

Schedule benefits were more readily cited. Process time savings were realized in time required to design, analyze, tool, and manufacture. Product cycle time is a significant metric. For example, the US automobile industry (Big Three) reported that with use of M&S tools and processes, they have reduced the cycle time (from concept approval to production) from five years down to three years and expect significant further reductions. Electric Boat has reported reducing the cycle time for submarine development from 14 years down to 7 years.

Productivity metrics from M&S use were easily noted: reduced effort in terms of man-years and number of workers; reduced number of intermediate steps, (i.e. mockups, redesign, engineering changes); reduced scrap; and reductions in manufacturing floor space. For example, the working drawings of the CH-53E Super Stallion aircraft's outside contours required 38 Sikorsky draftsmen approximately 6 months. The same task on the Comanche helicopter program required only one month's effort by one engineer using M&S.

Benefit examples in the quality/performance area revealed several metrics; proper assembly (good fit), reduced rework, reduced parts count, and early design evaluation prior to further design effort. Use of integrated Computer-Aided Design (CAD) systems by Northrop led to a first-time, error-free physical mock-up of many B-2 sections. Use of CAD also assisted in achieving first-time correct tube bends for expensive titanium electronic cable conduits.

While the primary objective of this study was to quantify the value of M&S in the DoD acquisition process, it was also recognized that the same research would surface data on challenges and opportunities that organizations and programs were encountering in effectively exploiting M&S tools within that process. Again, this information is representative of what the team encountered and not an all-encompassing effort to gather information on every acquisition program.

The challenges identified during the course of this research have been organized into three groups: technical, cultural, and managerial. While this grouping and their labels are somewhat arbitrary, and some challenges could be classified into more than one group, it emphasizes the fact that not all of the problems encountered in effectively using M&S tools in the acquisition process are technical in nature. A list of the challenges described in this report are presented in Table I-1.

As expected, some of the frequently encountered technical problems are interoperability of M&S tools, availability of data descriptions, security of data, and hardware and software limitations. Examples of each of these are given in Chapter IV. The technical challenges identified are not beyond the capability of improving technology to resolve, although prudent investments or proper encouragement might well speed and enhance the usefulness of the technical solutions.

Incentives for M&S use, availability of trained personnel, and acceptance of M&S tools and processes are among the cultural challenges the study team encountered while conducting this study. Resistance to change from an individual-based to a team-based approach and retaining technically proficient personnel are difficulties the acquisition community must overcome.

Proprietary data and model issues and resistance to funding verification and validation requirements are two common problems that the team perceived as managerial challenges. There is also a perception of inadequate guidance or direction for investing in M&S tools and processes.

Table I-1. Challenges for M&S in the Acquisition Process.

Type	Challenges
Technical	• Interoperability of M&S Tools • Availability of Data Descriptions • Security/Sensitivity of Data • Physics-based M&S • Hardware and Software Limitations • Variable Resolution
Cultural	• Acquisition Processes • Incentives for M&S Use • M&S Workforce • Acceptance of M&S
Managerial	• OSD and Service Guidance • Ownership of Data • VV&A Requirements • Funding Process • Use of System Models

E. Observations and Recommendations

There is real evidence of M&S tools and processes being used effectively and efficiently in select programs and activities in each of the services. Examples of early and continuous interaction between users, developers, and testers are evident in several programs. Use of M&S and virtual environments to quickly examine the impact and results of decisions have formed the basis for better decision making. Risk is better managed through the analysis of virtual mockups in virtual environments. There are examples of reduction in cycle time and greater flexibility in decision making through the use of M&S.

Industry and Government are cooperating closely in many areas pertaining to M&S and streamlined acquisition. In reaction to global or national competition and other pressures, many firms have modified their approach to product development, manufacturing, and support. Many of these firms, using M&S tools and processes extensively, have influenced the revolution in DoD acquisition, especially firms that are DoD contractors, and they are forging closer alliances through teamwork and IPT/IPPD initiatives. Most large system contractors cannot afford mistakes during development, thus rely increasingly on the capabilities provided by M&S. The result is an increase in number and influence of various consortia, Cooperative Research and Development Agreements (CRDAs), and dual-use efforts. These trends lead to greater cooperation and efficiency. The opportunities in which DoD can leverage current efforts are tremendous. A number of the ongoing programs which provide innovative approaches are summarized in Chapter IV.

One key effort is DARPA's Simulation Based Design (SBD) program. The goal of the project is to "revolutionize the Acquisition Process for complex military and commercial products" using distributed, collaborative virtual development environments. SBD considers all aspects of the system acquisition process, from mission analysis, through design and logistics considerations, to manufacturing and cost/risk analysis phases. The underlying premise is that M&S can reduce time and cost for all areas of the acquisition process.

Recommendation: Opportunities to cooperate with Industry such as the DARPA Simulation Based Design programs should be encouraged and continued. There appears to be great potential in partnerships such as the National Automotive Center where both the Government and Industry benefit from investigating new technology. There should be incentives to pursue business relationships such as these in order to utilize developing technology more efficiently.

A frequently discussed topic in the study team's visits was the need for investment early in the program for the tools that would be useful throughout the weapon system's life cycle. For programs such as the F-22 and the Comanche, there was no choice but to plan to invest early in M&S and plan their program around those investments. For many smaller programs the decision is more difficult. Guidance is general and there is little incentive for program managers to commit their early program funds to technologies for which they don't see an immediate return. This is complicated by the fact that there are no funding lines specifically designated for investing in the simulations necessary to support the acquisition process.

Investment in simulation facilities extends beyond the money invested by weapon system programs. The anechoic chambers at Edwards Air Force Base and Patuxent River Naval Air Station and the wind tunnel facility and computational fluid dynamics capabilities at Arnold Engineering Development Center are examples of these facilities. The Simulation Test Acceptance Facility (STAF) at Redstone Technical Test Center was funded by program managers, but is a facility that could be used with minor modification by other missile programs.

Recommendation: To meet the challenge of institutionalizing the use of available M&S technology, the Services must be committed to providing funds for M&S at the inception of the program. OSD and the Services should commit Science and Technology dollars to upgrade capabilities and facilities that could serve many weapon system acquisitions, and program managers should be encouraged to use these facilities instead of contracting to have new system specific facilities built.

There is currently no vehicle to get information on M&S capabilities and facilities to the programs that have the potential to utilize the assets. It would be useful to the program managers and to the Research and Development and Test and Evaluation activities to have a source for investigating M&S capabilities available within the Defense Acquisition community.

Recommendation: Develop an information source such as an Internet web page which would list capabilities in design; tools available, programs that have used them, activities they can contact for further information, etc. The same capabilities could be listed for testing; e.g.,

who does computational fluid dynamics, which facilities have wind tunnels and anechoic chambers, have any programs proven out this technology with their systems? The web page could also be used to identify innovative approaches in manufacturing and note those using virtual manufacturing environments.

The words are in place in DoD acquisition documents to support implementation of Simulation Based Acquisition, though there are some growing pains associated with implementation of this shift. For example, the Multiple Launch Rocket System program office submitted an Extended Range - MLRS Test and Evaluation Master Plan (TEMP), approved through the Army Staff, that was heavily supported by the results of simulation. The Office of the Director, Operational Test and Evaluation rejected the TEMP and directed that 36 more live rockets be fired than in the submitted plan. The issue is, to what degree can M&S replace or augment field tests? There is no universal answer, but the message received in part by the community is that the thought and guidance are there, but the implementation and acceptance are not.

Recommendation: DoD needs to institutionalize the use of models and simulations and insure that the community is knowledgeable about the tools available. The Services and OSD need to provide more responsive guidance relative to the advent of better and more useful simulation tools. Dialogue is needed within the Services and between the Services and OSD to effect policy on standardization. Program managers must overcome the management and cultural challenges that present barriers to the effective use of available technology.

The study found that program managers and their staffs are not well informed on M&S tools and their use in acquisition. Many program managers have had very limited exposure to models and simulations and would benefit from a short block of instruction which would emphasize the successes other programs have experienced by using M&S. Defense Acquisition University has begun to alter the curriculum in order to make the students more aware of the impact of using current technology early in the acquisition process and throughout the life cycle of the program.

Recommendation: Action is needed to provide focused information on the availability and capabilities of M&S to weapon system acquisition managers.

F. Summary

There is consistent evidence of M&S being used effectively in the acquisition process but not in an integrated manner across programs or functions within the acquisition process. Substantial evidence has been collected from individual success stories, though the benefits are not readily quantifiable into a general standard. The key is in focusing on the integration of M&S applications, across acquisition programs and throughout the process, not in exploring the applications themselves. In the final analysis, M&S will continue to grow in usage, capability and total contribution to the acquisition process. The opportunity exists now for the DoD to effect Simulation Based Acquisition by focusing on providing the opportunities to facilitate the change.

II. BACKGROUND

A. Objective and Approach

1. Objective and Key Issues

The objective of this study was to assess the effectiveness of the use of modeling and simulation (M&S) in the weapons system acquisition and support processes. These support processes include the systems engineering process, and evolving processes such as concurrent engineering (CE) and Integrated Product and Process Development (IPPD). The assessment addresses the following key questions:

- What are the metrics that can be and are being used to evaluate M&S effectiveness in the acquisition process?

- What specific M&S tools are emerging that are being used by Government and Industry to facilitate the design, development, manufacturing, test, and support of weapons systems in an IPPD environment?

- What are the associated benefits of using M&S in the acquisition environment?

- What are the key M&S challenges that remain that preclude the use of M&S in a seamless way within the acquisition process?

2. Approach

Recent and focused information on policy guidance and direction was obtained through a series of visits. Important M&S facilities and efforts were prioritized for potential visits in order to gather the best possible information on the use of M&S by field agencies. A list of the key offices and agencies visited follows in section A.3 of this chapter.

Issues important to the study were framed in the form of a focus paper which presented the desired questions in a flexible format. The goal was to avoid use of a survey or 'fill in the blanks' document in order to identify and come to terms with key substantive issues. The focus paper was normally tailored for each organization visited and was updated over the course of the study to include or highlight key issues. Previous assessment efforts and documents facilitated development of the focus paper. For example, the Acquisition Task Force on M&S (ATFMS) had placed significant emphasis on developing appropriate questions to be used during visits to a series of similar organizations. Such questions were used in order to capture issues key to the study's objectives.

The study team also conducted an extensive literature search on M&S initiatives and activities. This was conducted using local libraries, including the Pentagon's Army library, Defense Systems Management College (DSMC) library, SAIC's Corporate Technical Resource Acquisition Center, public libraries, the World Wide Web (WWW), the Computer Select system, and similar sources.

Interface with organizations and agencies involved in the systems acquisition process was the key step in becoming familiar with the breadth and depth of M&S use and related benefits, problems, and successes. By understanding the underlying policies and procedures, barriers, and metrics, the study team could gather the information necessary to focus on actual costs and benefits of M&S in DoD acquisition. While the intuitive and probably correct answer is that M&S benefits the acquisition process, this study sought the details to provide a more quantitative answer.

During several visits the study team interfaced with subordinate (labs, agencies, divisions, or offices) and tenant or affiliated (consortia, contractors, other) groups collocated with or near the main organization. On most visits, the study team was provided with significant amounts of material tailored to the questions in the focus paper, especially pertaining to metrics, new and evolving M&S tools, challenges, and costs/benefits. The team developed a summary of the visit from notes and data to ensure historical capture of key insights and observations. Copies of the summaries are on file.

3. Organizations Visited

Time and available resources limited the total number of visits, but many key organizations and individuals were visited during the course of this study. Their experience and insights were essential to gaining an appreciation of the benefits and the challenges associated with M&S, as well as developing a method to best quantify the benefits of M&S in the acquisition process. The organizations and primary POCs are summarized in Table II-1.

While specific reports of these visits are not included in this report, the data collected during the visits is incorporated and referenced throughout Chapters III and IV. We are grateful for the courtesies extended and the information shared in the many visits and discussions.

TABLE II-1: EXAMPLES OF KEY VISITS

SERVICE-LEVEL POLICY AND MANAGEMENT:

Deputy Under Secretary of the Army (Operations Research)	Mr. Walt Hollis
Special Assistant for M&S to Asst Sec of the Navy (RDA)	Mr. Ben Helme
Air Staff (AF T&E)	Maj. Bryan Ishihara
Office of Assistant Secretary of the Army (RDA)	Dr. Herb Fallin
Defense Advanced Research Projects Agency (DARPA)	Dr. Gary Jones
Army Staff, T&E Management Activity (TEMA)	Dr. John Foulkes
Office of Assistant Secretary of the Navy (RDA)	Mr. Mike Roberts
HQ, Naval Sea Systems Command	Mr. Dan Billingsley

R&D AND T&E ACTIVITIES:

Navy M&S War Room Project Management Ofc.
USAF Arnold Engineering Development Center (AEDC)
USA T&E Command (TECOM) and Aberdeen Test Center
Patuxent River Naval Air Combat Environment T&E Center
US Army Redstone Technical Test Center (RTTC)
USA Tank Automotive RD&E Center (TARDEC)
DoN/DoC Center of Exc. For Best Manufacturing Practices
Naval Air Warfare Center Weapons Div (NAWCWPNS)
Air Force Flight Test Center (AFFTC), Edwards AFB

PROGRAM OFFICES AND PEOs:

F-22
SC-21
AFATDS (Advanced Field Artillery Tactical Data System)
Army Tactical Missiles PEO (Program Executive Office)
COMANCHE
JSF (Joint Strike Fighter)
TOMAHAWK
NSSN (New Attack Submarine program)
Javelin
Longbow Hellfire
MLRS (Multiple Launch Rocket System)

SAMPLE INDUSTRY VISITS:

National Automotive Center (NAC)
Automotive Research Center (ARC)
Deneb Robotics, Inc
Ford Motor Company
Lockheed Martin, Palo Alto, CA
Sikorsky Helicopter
General Dynamics, Electric Boat Div
General Motors, Truck & Bus Div

B. Related Studies

Improvements in M&S tools to support acquisition are closely interwoven with initiatives to improve the overall acquisition process. The Packard Commission highlighted significant process flaws in their 1986 Report to the Congress. In 1993, then-Secretary of Defense Aspin and others, including Dr. John M. Deutch, proposed acquisition reforms bolder than those proposed by the Packard Commission. Also in 1993, now Secretary of Defense Dr. Perry, in Acquisition Reform: A Mandate for Change, described the problem areas in the acquisition process as follows:

> DoD's acquisition process is not sufficiently streamlined, flexible, agile, efficient, timely or effective. The acquisition community has not been sufficiently innovative, has not used technology to re-engineer itself, and has tended to use functional stovepipes rather than integrated decision teams.

Numerous recent studies have been conducted which deal with the benefits and limitations in DoD use of M&S in support of the acquisition process. Most of these studies were reviewed for their applicability to this effort and some ideas on how to measure the contribution of M&S were identified, but none directly addressed the effectiveness of M&S tools and processes in support of the acquisition process. More comprehensive summaries can be found in Appendix C.

C. Acquisition Guidance

1. OSD Guidance

Before examining how program managers are employing M&S, it is appropriate to review the guidance given by OSD to the Services, and in turn the direction the Services give to the acquisition managers.

The acquisition environment has many new challenges including downsizing, reduced funding, and the need to reduce the time and resources needed for integrating advanced technologies into new systems. The goal is to procure state-of-the-art technology and products 'better, faster, and cheaper' while also helping to transition DoD and its contractors to the new methods and tools that enable advanced acquisition.

Secretary of Defense Perry recently spoke at an Operational Test Agency (OTA) Commander's Conference and discussed five key themes: better use of M&S; focus testing where M&S can't be applied; combine tests (developmental and operational, or operational testing for two or more systems) when possible; combine testing with training or operations; and early involvement of testers.

In his keynote address to the Defense Modeling and Simulation Office Fifth Annual Industry Briefing on Modeling and Simulation in May 1996, the Under Secretary

of Defense (USD), Acquisition and Technology (A&T), Dr. Paul G. Kaminski, discussed the critical and increasing role of modeling and simulation in acquisition. He stated that:

> The bottom line is that integrated product and process development, backed up by a strong commitment to computer based modeling and simulation tools, provides a dominant competitive edge in the commercial marketplace and a clear warfighting edge on the battlefield. It provides a path for getting to market first and at a lower cost.

A recent interview with Philip Coyle, Director of Operational Test and Evaluation in OSD, in Program Manager magazine highlights some key areas of M&S emphasis. The key is to make testing more efficient. This can happen by involving testers early in the acquisition process, starting before the request for proposal (RFP) and during development of the operational requirements document (ORD). It also requires involving the OTAs and the Joint Interoperability Test Center (JITC) up front. He also identified the need for better use of M&S including tools that are more predictive (high probability of giving the right answer as a result of being based on real science, or 'physics-based').

DoD Directive 5000.1 encourages the use of M&S and states:

> Models and simulations shall be used to reduce the time, resources, and risks of the acquisition process and to increase the quality of the systems being acquired. Representations of proposed systems (virtual prototypes) shall be embedded in realistic, synthetic environments to support the various phases of the acquisition process, from requirements determination and initial concept exploration to the manufacturing and testing of new systems, and related training.

In addition, DoD 5000.2-R states:

> Accredited modeling and simulation shall be applied, as appropriate, throughout the system life-cycle in support of the various acquisition activities: requirements definition; program management; design and engineering; efficient test planning; result prediction; and to supplement actual test and evaluation; manufacturing; and logistics support. PMs shall integrate the use of modeling and simulation within program planning activities, plan for life-cycle application, support, and reuse models and simulations, and integrate modeling and simulation across the functional disciplines.

The DoD M&S Master Plan (DoD 5000.59-P) states the vision as follows:

> Defense modeling and simulation will provide readily available, operationally valid environments for use by the DoD Components:
>
> -To train jointly, develop doctrine and tactics, formulate operational plans, and assess warfighting situations.

-To support technology assessment, system upgrade, prototype and full-scale development, and force structuring.

-Furthermore, common use of these environments will promote a closer interaction between the operations and acquisition communities in carrying out their respective responsibilities. To allow maximum utility and flexibility, these modeling and simulation environments will be constructed from affordable, reusable components interoperating through an open systems architecture.

2. Service Guidance

Guidance for the use of M&S in weapon systems acquisition in the Services varies. The Navy employs different organizations to address oversight, policy, technical support, and use of M&S, because of the breadth of functional disciplines which Navy M&S supports. US Marine Corps M&S efforts are integrated into portions of the Navy's M&S structure and there is also a steering group and management office for USMC-specific functions and systems.

The Navy is establishing a PEO for Synthetic Operations, but the functions and responsibilities of this office have yet to be approved. The Navy also has a War Room for M&S for better integration of M&S functions and systems. Designed to work on M&S planning and implementation across the Navy, from initial requirements to system logistical support, the War Room also works on short term projects such as the Navy M&S Master Plan and the Navy's VV&A Instruction.

The Army Model and Simulation Office (AMSO) was charged with producing an investment plan that will focus on efficient M&S efforts. RDA is one of three domains established to support this office. This initiative was begun in 1995 and management is being implemented.

Office of the Assistant Secretary of the Army (OASA) for RDA policy memorandum, "Simulation Support to Army Acquisition," mandates use of a simulation support plan (SSP) for each Army ACAT I and II program prior to each milestone review. The long-term goal is to eliminate use of a separate SSP and integrate the M&S related information into the Acquisition Strategy Report. This will be another step in better integration of M&S into the overall acquisition process.

The Air Force has a long history of M&S applications and a growing need to improve on the use of M&S for decision-making. Significant organizational changes occurred in late 1984. The Directorate of Modeling, Simulation and Analysis (MS&A) (HQ, USAF/XOM) was designated the single point of contact for M&S. Within this organization several divisions provide support in the areas of evaluation, technical matters, warfighting, studies and analysis, operational requirements, and integrated product planning.

Most recently, the Air Force published a Functional Area Plan for Modeling and Simulation. Together with the New Vector initiative to guide Air Force M&S and the Air Force M&S Master Plan, published earlier this year, the Functional Area Plan provides the framework to integrate M&S into a single coordinated program.

D. The Traditional Acquisition Process

This section briefly summarizes the phases and milestones of the traditional acquisition process in order to create a baseline for comparison with the evolving process. The traditional process consists of distinct phases, starting with requirements generation or determination of mission need, and ending with the operations and support and eventually the retirement of the system. The phases are separated by milestone decision points where key decisions are made. These Milestone Reviews were often characterized as walls between phases which fostered a stovepiped approach that was evident throughout the process.

Most of the risk assessment was conducted early in the program, requiring use of imperfect assumptions and information (especially with regard to cost and technology). A result was imperfect expectations, and little flexibility in the system after the early stages of the program.

Members of the acquisition community who worked within this traditional process operated within their own sphere of influence with very little coordination before handing off the product to the next phase. This often fostered a situation in which different groups or teams had adversarial relationships. The Government, especially the user community, had very high expectations for the technology and the ability of the contractor to achieve success, sometimes unrealistically so. The test community played an oversight role ensuring that the evolving system met the user requirements to a suitable degree. On the other hand, the contractor and program manager sought to move the program along to the fielding or initial operational capability (IOC) stage. There was infrequent interaction between the various participants. User discovery of performance or capability shortfalls after fielding often led to expensive Engineering Change Proposals (ECPs) and modifications.

The traditional system resulted in a good examination of the final product, but failed to maximize efficiency, especially in light of the timing of requirements specification. While some M&S tools have long been employed in the acquisition process, they too were used in a stovepipe fashion with little or no use of common data across functional areas or across programs. Tools that are currently available to examine the system in a virtual manner were not available, thus a physical prototype was necessary to examine fit and function issues in detail before readiness for production.

Before the advent of integrated teams in the weapon systems development process, there was little effort made to combine testing to satisfy the different

requirements, or to collect extra data in early efforts so they could be used as part of the database later in the acquisition cycle. Dwindling resources and integrated teams have made program managers more aware of the value of integrating workers from different phases and using simulations and models to accomplish multiple missions.

In spite of being bound by processes and Milestone Reviews, the community is evolving the program offices and their support into an information team that shares data and results across the phases of the acquisition process. The positive results of simulation efforts in systems engineering have become evident in what we refer to as Simulation Based Acquisition. The developments and trends in each phase of the acquisition process that are affected by the immersion in M&S use are discussed in the next chapter.

III. SIMULATION BASED ACQUISITION

A. Introduction to Simulation Based Acquisition

M&S tools have been used to support the systems acquisition process, both in DoD and elsewhere, for a long time. As dramatic advances in the supporting technologies made those tools more powerful and less expensive, and as declining resources and changing priorities made it essential to find better ways to develop and field new systems, the use of these tools and of improved processes that exploit their contribution has expanded rapidly. It is not the purpose of this report to justify why the emerging M&S tools and processes should be used, but rather to cite documented contributions to the total acquisition process.

This use of M&S tools has increased in an evolutionary manner so that many would observe from their experience that 'nothing has changed, we have always used M&S tools.' In fact, much has changed and the rate of that change is increasing rapidly. This increase has not been imposed by fiat; it is not the result of new guidance or direction from top management. Rather it is the result of piecemeal adoption of powerful new emerging M&S tools to support existing processes and to satisfy emerging requirements.

As a result, these tools have been employed differently by acquisition programs at various stages of development in a seemingly ad hoc manner. Some programs are little changed from their processes of a decade ago while others are being radically transformed by changing processes that depend upon these tools. Most programs fall in-between, using M&S tools at some stages of their program's development with modification of existing processes. Program managers are utilizing M&S tools in areas where they see the greatest benefit.

Although it is not clear where this will lead the acquisition community in the next decade, it is clear that a revolution is underway and that the end result will be a new way of doing business. We will call this new approach to acquisition, "Simulation Based Acquisition," in order to differentiate it from the traditional approaches (Chapter II) and to emphasize its reliance on the tools and processes made possible by advances in simulation technology. It is not presented here as a specific, definable concept, but rather as a term to characterize the general approach of significantly increased use of M&S tools and the new processes which they enable in a new, more integrated approach to program development.

One area that can be impacted in a positive manner by the new acquisition approach is life cycle cost. It is well established that a large percentage of total system cost is determined by initial design decisions. Early system research and development (R&D) is usually only about 10% of total system cost but establishes the level of future production and operations cost. Relatively small investments, one or two percent of the life cycle cost of the system, could result in significant savings (greater than 25%) over the system's life. The traditional acquisition approach lacked the tools to conduct "what if" analyses to determine the impact of design decisions on future cost. These types of tools are now available.

The charter of this study was to document metrics, benefits, and problems associated with the use of these M&S tools in the acquisition process. To keep this effort focused, system requirements analysis and training and training device development were not included in the scope of this tasking. The programs investigated in this effort were at different stages of development, with none having used these tools yet in an integrated fashion throughout their development cycle. This study is consequently a series of independent stories, told in a familiar context. That framework is the acquisition process: concept development, engineering design and analysis, test and evaluation, manufacturing, and deployment and support.

The Simulation Based Acquisition (SBA) approach can generally be characterized as more flexible and integrated than the previous approaches which are often thought of as stovepipes. In a conceptual way, Figure III-1 shows the functions of the acquisition process without the fixed boundaries and with emphasis on their concurrent, integrated development. There is increasing interaction among all of the functions, a genuine concurrent approach, with data and expertise being shared and interacting throughout the entire process.

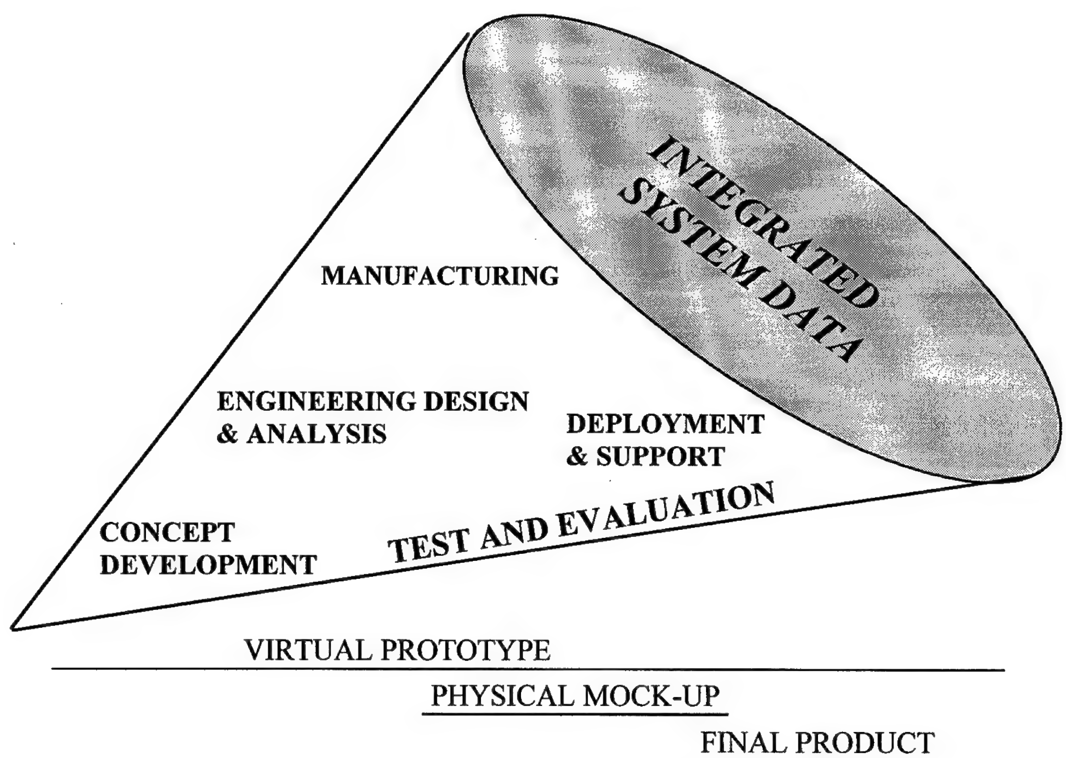

Figure III-1. Simulation Based Acquisition

The savings in simulation based acquisition are not always easy to quantify. As more programs document their success and experience using M&S in the acquisition process, there emerge four bins into which these measures of effectiveness can be categorized. These four areas of realized benefits are cost, schedule, productivity, and quality/performance.

It is worth noting that many reported cost savings are often illusionary. They are typically more correctly classified as "cost avoidance." As such, they are measures of significant additional work or results that were obtained using the M&S tools which would have cost the reported "savings" if they had been obtained by more traditional methods. This study has been careful to differentiate between cost savings and cost avoidance and to clearly identify the latter category when reported. Even if cost avoidance "savings" should not be properly measured in dollars, they almost always are an indication of improved system quality or performance or lowered program risk (e.g., smarter testing). In some cases, the program itself would not be economically feasible without these improved methods which provide adequate risk reduction for an affordable cost.

The approach of this chapter is, for each function of the development (systems engineering) process, to:

- describe how M&S tools are changing the acquisition process,
- identify metrics which validate the effectiveness of these tools in this process, and
- relate specific quantified examples of benefits of M&S tools in this process.

While the following benefits are described within a functional area because of their similarity, and to emphasize the value of M&S tools and processes within that function, it is recognized that product cycle time is a major (top level) metric of great significance. For example, the US automobile industry (Big Three) report that with use of M&S tools and processes, they have reduced the cycle time (from concept approval to production) from five years down to three years, and expect significant further reductions. Electric Boat has reported reducing the cycle time for submarine development from 14 years down to 7 years.

The next chapter will relate technical, cultural, and managerial challenges which prevent programs from realizing the full benefit from these M&S tools.

B. Concept Development Process

Concept development is the analysis of operational requirements and their transformation into functional requirements for a new system. Alternative approaches to satisfying the requirements are evaluated to select the best general approaches to a system solution.

1. Tools in the Evolving Concept Development Process.

Because this stage of development is, by nature, almost totally conceptual, it has always relied upon graphical and data representations (models) of proposed alternatives. Computer tools

to support this process have benefited from the recent growth in power and reduction in price of hardware and software which allows the cost effective analysis of far more alternatives than was possible previously. More significantly, M&S tools have benefited from efforts to integrate related tools which enable more extensive analysis of alternatives in a more realistic operational environment. Though the operational environment is virtual, recent progress in developing and making available appropriate realistic and validated virtual environments has been significant and provides the necessary credibility to emerging processes that use these tools.

The ability to develop digital master product models with Computer-Aided Design/ Computer-Aided Manufacturing/Computer-Aided Engineering (CAD/CAM/CAE) software technology has made it possible to more fully understand products from a manufacturing standpoint during the early design stage. The depth and richness of the product information contained in a digital master model makes it easier to more fully communicate detailed information to everyone involved in the product development process.

Digital master models help to develop and evaluate multiple design concepts so that the material solution most efficiently meets user needs. Quality becomes part of the design process itself and can be built-in instead of added-on. Digital master models provide details about the product's shape, behavior, and cost before the fabrication of costly physical prototypes, and help minimize scrap, reduce downtime, and eliminate wasted or redundant operations. This approach allows teams to work concurrently by providing common ground for interrelated product development tasks. Instead of individuals creating one piece of information at a time, the digital master model enables various disciplines to work together much earlier in the product development process.

One intangible, but important benefit of the new M&S tools is the ability to quickly and effectively communicate information on how a new concept will look and function to senior decision makers.

2. Metrics.

- money/effort saved in programs that are canceled/terminated early
- rapid and early proof of concept prior to more detailed stages of design
- better input from users on the impact of concept design decisions

3. Benefits of M&S.

a. Several joint and Air Force warhead/munitions programs were terminated early in concept development, before expending resources wastefully, due to improved analysis of system lethality using M&S tools:

- Wide Area Anti-Armor Munitions (WAAM) - $30M program,
- Hypervelocity Missile - $10M program,
- Kinetic Energy Penetrator (KEP) - $50M program,

- JP-233 Runway Attack Munition - $54M program, and
- Boosted Kinetic Energy Penetrator (BKEP) - $130M program.

b. Vehicle concepts have been terminated or not further explored due to mobility, firepower, or vulnerability problems discovered early using TARDEC's Tracked Vehicle Work Station (TVWS), which creates and evaluates new concepts in a virtual environment.

c. Several Navy programs (NSSN, LPD-17) have explored initial concepts for overall viability and crew/functional acceptability (sizing, location) prior to further design effort. Examples are crane selection and helicopter control station window design for the LPD-17, along with assessments of cargo locations and on-board vehicle movement. For NSSN, maintenance accessibility for personnel and for machinery removal was evaluated early in the design.

d. The Department of Energy (DoE) at Oak Ridge, TN, reported analyzing many 'bright ideas' with M&S tools since they were too expensive to physically check out. Ultimately, all the concepts were rejected as flawed based upon these analyses.

C. Engineering Design and Analysis Process

The design process is well understood from its long tradition of engineering education and experience. The graphical and computational tools that support it have evolved slowly, but the computer revolution has also enabled significant changes in recent years. Slide rules have essentially disappeared for faster and more reliable computational tools, but engineering drawings and representations of components, subsystems, and systems as a means to communicate system design are still widely used.

1. Tools in the Evolving Engineering Design and Analysis Process.

This past decade has witnessed the emergence of computer tools to assist this process, primarily in the domain of CAD/CAM/CAE tools. These tools automated some of the manual tasks of developing graphical and data representations of systems, but they remained at the individual engineer or small functional design team level of use.

Driven by the commercial marketplace, these CAD/CAM/CAE tools have improved greatly, but it is the integration of these tools and the changing of processes which utilize these tools that is beginning to produce significant results. When the entire design team, to include manufacturing, support, and test activities, as well as subcontractors, are linked in a meaningful fashion to this common database, a genuine concurrent approach to development is possible. The various members of this design team no longer need to be collocated. Technology now allows each to work from their own locations in an effective, distributed manner. Far more design alternatives can now be developed and analyzed for performance and cost impacts before finalizing design decisions.

In addition to an integrated team approach to system development, as confidence in the validity and accuracy of these tools has increased, the requirements for elaborate and expensive physical prototypes of the new system have relaxed. Very expensive physical prototypes are no longer the only way to ensure that integration and fit requirements have been satisfied. Virtual prototypes are proving to be acceptable representations for evaluation of many system integration issues.

2. Metrics.

- number of people required to accomplish design tasks
- time required to accomplish design tasks
- number of physical mockups or prototypes that are required
- number of parts or complexity of the final design (i.e., simplicity)
- reduction in first article assembly effort

3. Benefits of M&S.

a. In the DARPA Initiative for Concurrent Engineering (DICE) program, TRW Corporation redesigned a radar warning system using two different approaches: traditional and concurrent design with integrated design automation. The traditional approach required 96 man months while the advanced approach required only 46 man months.

b. TARDEC prepared an engine replacement analysis for the Bradley Fighting Vehicle (BFV) system using half a man month with M&S tools compared to the traditional approach which required 4-6 man months to accomplish.

c. TARDEC designed a new low silhouette tank prototype using 14 engineers in 16 months. Traditional approaches have required about 55 engineers and 3 years.

d. General Electric used a new parametric modeling approach to design a new engine fan blade, thereby reducing the process time from up to four weeks to a few hours.

e. New integration techniques employed by Martin Marietta (now Lockheed Martin Corporation) using M&S tools and processes resulted in:

- reduction of engineering time to construct mock-ups from 2,100 hours to 900 hours ,
- cutting the number of tool designers required from 10 to 4,
- reduction of physical electronic board development iterations from 2.5 to 1.5, and
- reduction of the number of changes per final drawing from 4 to 2.2 for a savings of about $108M per year.

f. Lockheed Martin used solid modeling and computer simulated assembly for aircraft parts design which allowed:

- elimination of some physical mockups at $30M each,

- cost reduction in design/verification steps of 30-50%, and reduction in first article (and subsequent) assembly costs of 20-25%.

g. The AS400 computer development program by IBM used extensive simulation and cross-functional teams to simplify design and reduce the part count to 4000 as opposed to 10,000 for the earlier S/38 computer. They used a simulator to test software design alternatives until they converged upon a virtually defect-free design, and did this in about two years -- less than half the time required for its predecessor machine. About 10 months of the two-year design cycle reduction was due to the use of design simulation.

h. Through advanced integration techniques, Motorola achieved the following gains:

- a 50% reduction in design cycle time for end products using Application Specific Integrated Circuits,
- five-week to one-week reduction in printed circuit board supply and assembly cycle,
- cellular communications product cycle reduced 50%.

i. Sikorsky Aircraft employed 38 draftsmen for approximately six months to produce the working drawings of the CH-53E Super Stallion aircraft's outside contours. The same task on the Comanche program only required one month for one engineer using M&S tools. In addition, precisely designed parts from different contractors assembled properly on the first attempt and required a minimum amount of rework.

j. The Comanche PM Office mandated early use of mission and engineering simulators to examine operational characteristics. The Comanche Simulator and Surrogate Aircraft Fly-Off for source selection cost about $20 million, versus about $500 million for the prototype aircraft fly-off for the UH-60 Blackhawk.

k. Seakeeping analysis in support of ship design by Naval Sea Systems Command (NAVSEA) in 1985 took about 27 days. In 1994, the same analysis was conducted in 3.5 days using better M&S tools operating interactively.

l. Radar cross section (RCS) analysis and treatment for ship design by NAVSEA took about 57 days in 1990. Using new M&S tools and processes, the Navy now can conduct the same analysis in 16.75 days.

m. Newport News Shipbuilding reported improved M&S tools and processes reduced engineering design time by 40% and tooling time by 23-27%.

n. Boeing designed a new strut for the 767 using an all-digital data process in 17% less time, saving 30,000 man-hours, than previous approaches. They also had a 65% decrease in design changes.

o. LPD-17 saved $6 million in design costs by using new M&S tools. It also saved 100 tons in topside weight which is expected to greatly improve performance.

p. Boeing's 777 program exceeded its goal of reducing change, error, and rework by 50%. Parts and systems fit together better than anticipated and at the highest level of quality. On the first 777 aircraft assembled, the final body joining tolerance was just 0.023 inch away from a perfect alignment compared to the typical half inch experienced in previous programs.

D. Test and Evaluation Process

Testing new systems has long involved using the production hardware in a live environment. Testing of defense systems for their ability to meet operational requirements has emphasized the use of typical operators in an operationally realistic scenario and environment. The increasing use of simulators to focus the scope and reduce the cost of testing actual hardware and software demonstrate early movement toward the incorporation of M&S tools and processes.

1. Tools in the Evolving T&E Process.

The senior levels of the Defense Department are now consistent in their support of increased use of M&S tools in the T&E process because of the promise inherent in those tools to help meet the challenges of reduced resources mentioned above as well as focusing the scope and improving the quality of the test process. In recent years there has been continuing dialogue about how to best incorporate those tools, with the underlying issue of the credibility of the tools being a major constraint. At a minimum, the early involvement of the T&E engineer in the concept development stage, to ensure that functional requirements are formulated in a testable manner, is facilitated and aided by M&S tools. Similar tools are now widely used to plan, rehearse, extend, and evaluate live T&E activities. To a significant extent, assessment of a system is now possible using M&S long before a physical prototype is actually constructed. Physics-based dynamic models using CAD descriptions of the system in a test-validated environment now provide critical feedback to system designers, as well as users, as the design matures.

For example, the first flight of a new aircraft is preceded by years and hundreds of millions of dollars of mathematical modeling, flight simulations, hardware-in-the-loop (HWIL), software-in-the-loop (SWIL), and other simulations.

M&S is being integrated with testing as part of a strategy to provide information regarding risk and risk mitigation, to provide empirical data to validate M&S, to permit an assessment of the attainment of technical performance specifications and system maturity, and to support determination of whether systems are operationally effective, suitable, and survivable for intended use. In operational testing, M&S is used to complement the testing of systems in an operational environment by extending the scenario or the environment to make it possible to assess additional situations.

The Air Force Flight Test Center (AFFTC) at Edwards AFB reports a situation common to other Research, Development, Test and Evaluation (RDT&E) Centers and PM Offices. The "savings" resulting from use of improved M&S tools and processes is not realized in dollars, or

in less test flights or test time, but rather used to address additional issues that otherwise would not be tested because of limited flying hours and resources available.

One of the primary benefits, especially for aircraft test centers, is avoiding the "cost of failures." This cost avoidance is extremely important to the development programs, and includes the incalculable cost of risking the loss of life of test personnel. The following hypothetical example of a missile program will illustrate some aspects of the "cost of failure."

Assume that: a flight failure causes a two month program delay; the cost associated with this delay is the monthly spend rate times two; the monthly spend rate is $5 million; 40 live missile flights are required for the test; there is a 90% success rate of missile flights. Then a two month slip will cost the program $10 million and four failures (40*[1-0.9]) are expected for a total program cost of $40 million. If the M&S tools are able to prevent half of the failures, a cost savings of $20 million is realized.

2. Metrics.

- number of areas assessed that are difficult/impossible to test physically due to limitations in cost, time, or manpower, or due to risk to humans, equipment, or the environment
- quality and quantity of test data gathered
- amount of testing concurrent with development
- stimulation realism (creating a realistic number of effects with fidelity)
- cost avoidance (for test article as well as test resources)
- number of programs retained (i.e., avoid program termination)
- number of safety problems resolved before human testing

3. Benefits of M&S.

a. The Tactical Missile Signature (TMS) center and database at Arnold Engineering Development Center (AEDC) reports that obtaining the measurements for various missile characteristics can cost up to $700,000 per missile to set up, fire, and collect and reduce the data. Equivalent data can be obtained using M&S tools for less than $10,000.

b. The F-22 program used AEDC's integrated T&E (IT&E) concept to address the need to safely separate fuel tanks and weapons from the aircraft over a range of flight conditions. Modeling of the pylons and the maneuvering aircraft were combined and compared to wind tunnel model scale data. The degree of correlation validated the approach and allowed ground simulation results equivalent to flight conditions. The IT&E approach met the goals of reduced cost and increased information to reduce program risk. In addition to providing the information, this approach saved the F-22 program a verified $8 million.

c. AEDC used combined computational fluid dynamics (CFD) and engineering methods to predict the separation of the Pegasus XL rocket booster from an L-1011 Tristar aircraft without having to conduct wind tunnel testing that would have cost about $750,000.

d. Testing of stockpiled munitions, for systems such as HELLFIRE and Javelin, is required to ensure their reliability after storage. M&S techniques coupled with non-destructive electronic component testing has dramatically reduced the number of live missile firings required to certify reliability of a stockpiled lot.

e. Advanced Medium Range Air-to-Air Missile (AMRAAM) testing at the Guided Weapons Evaluation Facility (GWEF) at Eglin AFB used M&S to simulate between 16,000 and 17,000 missile software and hardware tests. This testing was not feasible using live firings due to the high cost (about $3M for each missile). The needed data could not be obtained unless M&S was used.

f. Navy in-water torpedo testing can cost from $50,000 to $80,000 per firing, while the used of simulation can allow 100 to 300 tests to be run for the same price.

g. Navy live-fire missile testing produces fewer than 100 data points on average, and hundreds of thousands of such data points are needed to adequately describe missile performance envelopes. Since fewer than 25 valid live firings are usually affordable, the only alternative is the use of simulation.

h. An analysis of the HWIL facility at Point Mugu, CA for AMRAAM testing claims a cost avoidance of $2,500 million a year (assuming that 8,400 (the number of simulated firings) live firings per year was feasible). The same analysis reveals that the Weapons Software Support Facility (WSSF) at China Lake provides a cost avoidance of about $10 million a year. WSSF is used for integration, checkout, and V&V of avionics software with actual avionics hardware operating as a total aircraft system. The conclusion is that it is impossible to rigorously test systems as complex as F/A-18 avionics without this type of facility, not only from the point of view of cost, but also with regard to safety, accuracy, environmental concerns, security/stealth, training, and other factors.

i. During SIMNET/AIRNET Developmental and Operational Testing for Army helicopters, two Non-Line of Sight (NLOS) simulators were built and compared with captive flight and actual missile firing tests. The results showed that total costs for the necessary testing was about $6.65M for captive flight, $8.8M for live missile firing, and $2M for the simulators. The simulators had major advantages in the number of trials that were completed, and the reduced time and number of test personnel required.

j. The US Army Missile Command (MICOM), RD&E Center, Advanced Simulation Center Hardware-in-the-Loop Simulation Facilities, claim total cost savings/avoidance that exceed $270M.

k. US Army TECOM has documented the following benefits derived from M&S, for ground weapon systems:

- The Firing Impulse Simulator (FIS) simulates the recoil/trunnion loads and ballistic shock effects for tank and howitzer cannons. The investment cost was almost $7M, but the FIS saves about $2,000 per round or $23M in cost avoidance for a typical trunnion bearing test. There are also savings from reduced personnel (13 to 4), time savings, and reduced environmental problems in terms of noise, blast, and toxic fumes for each test.
- The Moving Target Simulator (MTS) assesses the ability of tank and other weapon crews to track and fire on simulated maneuvering targets (represented by projected laser spots). The MTS saves about $1.5M per year compared to field tests, and also significantly reduces time spent on test, redesign, and retest.
- Bridge durability testing was once done by 3,000 actual crossings over a period of 12 weeks and at a cost of about $325,000. Such tests are now conducted using a mix of actual and simulated crossings based on instrumented degradation. The new method reduces cost to about $110,000 and time to about 9 weeks.
- Vibration Test Facility (VTF) shaker tables can now replace actual miles driven by combat vehicles to determine the effects of vibration. This saves costly field testing, as each tank hour of driving costs about $1,200.
- Target Acquisition Model Improvement Program (TAMIP) provides an objective means for comparing the vulnerability of vehicles to detection on the battlefield. The models quantify the value added when vehicle signatures are reduced. Included in TAMIP improvement are millimeter wave, infrared, visible, and acoustic models.

l. The AFFTC at Edwards AFB, CA, primarily conducts developmental flight tests to clear aircraft and electronic warfare (EW) systems for operational testing. Benefits are significant, but hard to quantify:

- Immediate cost savings from M&S use in flight test are not significant compared to the long term (cost avoidance) savings to the program from more effective and timely elimination of problems, especially before fielding the aircraft (after which changes become very expensive).
- M&S tools are essential to investigating issues of flight safety before live range testing with humans.
- In recent years using M&S tools at Edwards, there were no major problems encountered in live flights that were not identified early in pre-test simulations by those tools.
- M&S helps to focus the available test time much more productively and reduces risk.

m. NAWCWPNS, China Lake, CA, is the Navy's full spectrum RDT&E and in-service engineering center for weapons systems associated with air warfare (except antisubmarine warfare systems), missiles and missile subsystems, aircraft weapons integration, and assigned airborne EW systems. A range of facilities within the NAWCWPNS provide important data in the areas of target signatures, acquisition and tracking, end-game geometry, weapon lethality, proximity sensor detection characteristics, target resistance to fusing, avionics integration, pilot interactions, radar and sensor integration, GPS integration, situational awareness, rules of engagement, radio frequency (RF) and infrared (IR) signatures, and other types of data. Identified benefits include:

- M&S is an enabling tool without which much of the acquisition process cannot be accomplished as it allows understanding of engineering and operational issues including difficult systems integration issues; assessment of scenarios which are impossible to actually test; and evaluation where security considerations preclude 'open air' testing.
- M&S avoids the cost of some live fire test failures which typically result in program schedule slips and unanticipated costs, or high visibility failures which threaten life as well as program viability, and other aspects of risk.
- M&S avoids Software Support Activities (SSA) startup costs after production ends.
- M&S reduces costs by focusing test firings.

n. Sikorsky projects that for the Comanche helicopter program they will save $673M through the use of virtual prototyping over actual flight test hours involving crew station and flight controls design, major equipment integration, air worthiness qualification and training.

o. A vulnerability assessment was required for each of the 15 primary targets for the Joint-Service Standoff Weapon (JSOW). The Navy conducted full-scale tests on only three of the targets to validate and calibrate M&S tools. The tools were then used to conduct the analyses of the remaining 12 targets without further full-scale tests. This approach saved more than $2.5M.

p. At AEDC, M&S has been used to help lower the cost of testing to the customer. Average time in the PWT-16T wind tunnel has decreased from six weeks to 3-4 days.

q. At Eglin AFB, use of PRIMES (Preflight Integration of Munitions and Electronic Systems) ground simulation led to a 35% reduction in cost and a 300% increase in data capture during a recent flight test program of the APG-63 radar.

r. The Patuxent River Naval Air Warfare Center Aircraft Division (NAWCAD) used state-of -the-art simulation and ground test capabilities to reduce flight test hours and costs by a third while evaluating ALQ-99 receivers and ALQ-149 communications countermeasures equipment on board the EA-6B aircraft.

s. The F-16 program has used AFFTC M&S facilities to evaluate avionics and electronic suites since 1990 as a replacement for and complement to flight test programs. Approximately $40.8 million have been saved on flight tests with this approach.

t. M&S tools were used to test the F-15 radar, providing three times the data at a third of the cost compared to open air range testing. A small number of flight tests were used to validate the results.

E. Manufacturing Process

Emphasis and investment in automation has improved the efficiencies of the manufacturing process, but its lack of integration with other development processes is the root

problem. Particularly in the defense industry where emphasis is on design and innovative technology, manufacturing has suffered in priority and emphasis.

1. Tools in the Evolving Manufacturing Process

The primary contribution of emerging M&S tools is not in improved manufacturing technologies, but rather in bringing manufacturing expertise to the design processes so that the final design is more manufacturable. Improved manufacturability offers significant potential payoff.

In addition, M&S tools can assist the manufacturing team in designing the manufacturing process for a new system just as the design team is developing the design. The equipment, work flow, and overall process for manufacturing can now be developed and analyzed in a virtual environment with high confidence in the results.

2. Metrics.

- number of available options to improve cost, schedule, performance, etc.
- reduction in number of manufacturing process steps and time
- better part and assembly fit resulting in less need for rework
- reduced labor costs including fewer meetings and data submittals
- reduced amount of scrap and waste material

3. Benefits of M&S.

a. The Comanche program used the Computer Aided Three-Dimensional Interactive Simulation (CATIA) package to improve on the traditional design and manufacturing processes. For joining the fuselage and tailboom, this facilitated a two-step tooling process versus an eight-step process as experienced in the CH-53 program without use of CATIA. It also achieved 95% first time fit versus 35% in previous processes, and reduction of labor cost for the joining from 19 man-years to one man-month.

b. The Joint Strike Fighter (JSF) PM Office and McDonnell Douglas conducted a six-month side-by-side comparison of traditional versus virtual manufacturing (VM), involving redesign of the F-15E mid-fuselage airframe former. Benefits attributed to the VM approach were:

- 33% reduction in design release time,
- 27% reduction in cost,
- 19% reduction in manufacturing cycle time,
- 20% reduction in factory floor space use,
- a higher quality production part including 24% reduction in parts count and 78% reduction in fasteners required for assembly.

The JSF PM Office projects the benefits of VM offer a potential savings of up to 3% of life cycle costs which could equate to $5 billion.

c. Through computer-based concurrent engineering and improved communications within and among design teams, Intel Corporation has reduced the time for hardware from design-to-sample in half, even though product complexity doubled. In addition, the company has achieved a 95% success rate on the first silicon fabrication of new products.

d. For the Army's Flexible Computer Integrated Manufacturing (FCIM) program, the Electronics Module communications end items effort has resulted in:

- 66% reduction in cycle time,
- $3 million in cost savings,
- $3.8 million in cost avoidance.

e. Electronically integrated data among several departments permitted Ford Motor Company to increase its quality such that there was a 10-15% cost reduction and a 14% reduction in time for sheet metal production. Currently, Ford is on track toward its goal of 90% reduction in the number of prototype manufacturing models that it must build.

f. The use of integrated CAD systems by Northrop led to a first-time, error-free physical mock-up of many B-2 sections. Use of CAD also assisted in achieved first-time correct tube bends for expensive titanium electronic cable conduits.

g. Boeing Corporation, using new M&S tools and processes on the 777 aircraft, was able to make necessary tooling changes with only two engineers instead of 40 engineers required for previous aircraft.

h. Boeing reports that their 747 required over 10,000 shims to compensate for ill-fitting parts while the 777 requires fewer than 50 shims. After leaving the assembly line, the 747 required many hundreds of workers to complete unfinished tasks, while the 777 required only a few workers.

i. Boeing reports that scrap was reduced by 30% on the 777 compared to the 747. Rework was reduced from 30% on the 747 down to 3% on the 777.

j. The JSF program reconfigured one component that was initially comprised of 250 parts into a design of only 25 parts which significantly reduced manufacturing and support costs.

F. Deployment and Support Process

Operation and support (O&S) of a deployed system typically requires a majority of the total life cycle costs of the system. The cost of maintaining the system is a function of many factors including the maintenance time required, and the production and storage costs of repair

parts. Too often these O&S costs have not been adequately considered by the design team which is driven by operational performance requirements.

1. Tools in the Evolving Deployment and Support Process.

As in previous phases, the significant change made possible by the use of M&S tools is to integrate these O&S functions into the total system development process. That primarily means considering the implications of these functions on the concept which is selected and the design which is developed to satisfy operational requirements. Not only can operational use be evaluated during the design stages to minimize the subsequent necessity for modifications to the fielded systems, but the support requirements for those systems can be better analyzed during the design stage to lessen the support burden and thus the total life cycle costs of the system.

2. Metrics.

- time to evaluate Operations and Support (O&S) costs and issues
- time to analyze/create O&S requirements such as planning documents
- amount of data stored and accessed
- number of legacy designs, products, or tools re-used

3. Benefits of M&S.

a. The Navy's Smart Product Model (SPM) is designed to support all phases and functions of acquisition including O&S needs. For the NSSN program, early analysis of form, fit and function integrates representatives from the fleet in order to ensure they can provide input to how design and manufacturing will impact future maintenance and support activities.

b. Lockheed Martin Corporation indicates that M&S support in the areas of supportability evaluation will reduce maintenance man-hours by up to a factor of three.

c. Electronic integration by Northrop permitted the reduction of provisioning list release time from six months to 60 minutes.

d. For the McDonnell Douglas AH-64D Longbow Apache program, the Engineering Development Simulator (EDS) was initially used for the source selection effort, then was further developed and verified and validated to support development, prototype production, and testing. The EDS or legacy systems built upon the EDS such as the LCT (Longbow Crew Trainer) are now used for aircraft training. The MAVWEST (Multiplex Armament Visionics, Weapons and Electrical System Trainer) uses hardware and software developed for the LCT and other early legacy systems. MAVWEST is used for high complexity maintenance training for a range of systems including fire control radar, armament, navigation, and communications.

e. With the Navy's focus on life cycle maintenance, new M&S tools have helped to reduce the standard parts list from about 95,000 for the Seawolf class submarine to about 16,000 for the NSSN.

f. A study of the impact of a common data management, storage, retrieval and exchange service for transferring in a standard digital format all contractor design and manufacturing data among the Air Force and its B2 subcontractors found significant savings. This study, "CALS Contractor Integrated Technical Information Service (CITIS): Business Case Feasibility Study," determined that the CITIS would lead to:

- 50% reduction in attendees at meetings between contractors and the Air Force,
- 5.4% reduction in the total B2 spare parts dollars,
- 23% reduction in modification lead time,
- 1.8% increase in the average availability of the aircraft fleet, and
- 90% reduction in the contractor data submittals.

The total estimated cost savings ranged from a minimum of $536M to a maximum of $894M, for investments that ranged from $9M to $30M.

IV. CHALLENGES AND OPPORTUNITIES

A. Introduction

While the primary objective of this study was to quantify the value of M&S in the DoD acquisition process, and that was addressed in Chapter III, it was also recognized that the same research would surface data on challenges and opportunities that organizations and programs were encountering in effectively utilizing M&S tools within that process.

Not surprisingly, the challenges that are being encountered by users of the tools are far easier to capture than quantifying the value of M&S tools in the acquisition process. Every organization has a list of problems that need to be resolved, and many of them have common roots. It is beyond the scope of this study to develop a complete list of issues, the solution to which would result in the optimal use of M&S tools to seamlessly enhance the acquisition process, but key issues are identified and discussed in the following pages.

The technical challenges identified in this chapter are not beyond the ability of improving technology to resolve, although prudent investments or proper encouragement might well speed and enhance the usefulness of the technical solutions. Cultural and managerial issues are often more difficult to overcome, but because they are often the product of current incentives, both negative and positive, built into the acquisition process, there is reason to believe that effective solutions are available.

In addition, there are many noteworthy initiatives currently underway which offer promise for improving the technologies and processes which support DoD acquisition. Some of those are summarized at the end of this chapter.

The intent of this chapter is to identify and describe or explain those challenges and opportunities to the extent necessary for the reader to gain understanding. Specific findings and recommendations are deferred to Chapter V.

B. Challenges

The challenges which were identified in this research have been organized into three groups: technical, cultural, and managerial. While these groupings and their titles are somewhat arbitrary, and some challenges could be classified into more than one group, it emphasizes the fact that not all of the problems in effectively using M&S tools in the acquisition process are technical in nature. In fact, the majority of the challenges are caused by the processes in which the tools are employed, and by the experience and understanding of management in using these tools.

While technical issues are a reasonably obvious category, the difference between cultural and managerial issues is somewhat less distinct. The general distinction in this chapter is that cultural issues are related to work processes, worker incentives, and education and training.

Managerial issues are related to official guidance, management direction, and organizational design.

1. Technical

a. Interoperability of M&S Tools

(1) Issue: A data model of a system does not operate seamlessly with the M&S tools across the spectrum of functional areas in the acquisition process.

(2) Discussion: As described in previous chapters, these M&S tools have been incorporated piecemeal into functional areas of the acquisition process. Historically, new data descriptions of the system were developed to support each M&S tool. The great advantage of using the same (evolving) data description throughout the development and fielding of the system is that it has led to increased effort to package or translate the data description so that it is usable by many (if not all) of the M&S tools in the other functional areas. While this is technically possible in most cases, it is unduly expensive and time consuming. Many translators have been developed between various types of M&S tools, but, as these tools are upgraded or enhanced, the translators often need to be significantly reworked at great expense of people and time. The increased use of commercial-off-the-shelf (COTS) CAD/CAM/CAE packages has both helped and exacerbated the situation because there are still several different data standards in use by those developers.

(3) Examples:

- TARDEC often requires manual reprogramming to go from one functional area to another, e.g., from design to performance modeling, to man-in-the-loop, to production analysis.
- TARDEC has developed translators from CAD design packages (Intergraph) to their performance M&S tools, but updates to Intergraph then require extensive work to update the translators.
- TECOM notes that one of their biggest challenges is the development of standard interfaces between M&S tools, especially the output of CAD data directly into dynamic performance M&S tools.
- The SC-21 Program is concerned that there are too many uncertainties regarding future protocols, standards, architecture, and infrastructure for M&S tools and data. It is a detriment to their ability to plan and develop an effective integrated M&S approach to supporting the acquisition process.
- The AFATDS Program notes that most digital systems and data are not joint or interoperable. Standardized data, below the architecture/infrastructure level, is needed to make M&S tools work easily with each other.
- AEDC has the same concerns, but does have some engineering level M&S tools that integrate well with each other and with certain campaign level tools. They do a great deal of work directly with industry and need the flexibility to work with various data packages.

- LPD-17 program asked for design databases from the six competing contractor teams. All six used different database systems and none were interoperable with the system in use at the Program Office.
- The National Automotive Center (NAC), a TARDEC consortia with industry, is attempting to develop a collaborative program with the Big Three US automobile manufacturers and the major ground vehicle manufacturers to implement an Automotive Product Development Framework to help solve this interoperability challenge.
- Ford Motor Company has purchased and implemented a standard CAD/CAM/CAE approach company-wide to overcome this challenge.
- Deneb reports that corporations which have made a heavy investment in internal proprietary M&S development consider it a competitive advantage and become resistant to COTS approaches.

b. <u>Availability of Data Descriptions</u>

(1) Issue: Adequate data descriptions of current weapon systems are often not available for M&S support of the system upgrade/product improvement process.

(2) Discussion: Data descriptions of currently fielded weapon systems present a special challenge because of the time that has elapsed since their original design and manufacture. Differences in contract requirements, tools to develop and maintain data descriptions, and the changing contractor environment of mergers and focus on DoD business, result in a potential tangle of difficulties as those systems are identified for major upgrades instead of designing a new system to replace them. Lack of availability of an adequate data description of the current system will add significant cost to the design and development of any upgrade as well as limiting full contractor competition in that process.

(3) Examples:

- TARDEC is now supporting the upgrade of many currently fielded vehicle systems, and expects to support many more in the future, for which only the original contractor has a data description. It is very expensive for TARDEC to develop an adequate, vector-based description of the system for their use in M&S dynamic analysis of design concepts and tradeoffs.
- AFFTC Edwards experiences situations where no system model exists, or the Edwards staff is unable to understand or use the model provided.

c. <u>Security/Sensitivity of Data</u>

(1) Issue: Situations exist where system data must be kept separate from competing contractors or secure from non-US subcontractors while still being consistent and available to the US Government.

(2) Discussion: Early involvement of multiple competing contractors in the design and development process of a new weapon system is highly desirable, if not essential. However, the evolution toward a more integrated process across a distributed environment using

M&S tools and a common data description of the new system complicates the need to provide adequate protection for proprietary information and processes. There are also frequent situations where a US prime contractor needs to share M&S tools and processes with non-US sub-contractors, but certain data must be protected in the process.

(3) Examples:

- SC-21 has a need to keep a proprietary security wall between the M&S data of competing contractor teams while encouraging their full participation in the design and development process utilizing a common database.
- NAWCWPNS China Lake reports programs with non-US subcontractors where special "sanitized" versions of system models and associated data were required to support their involvement in the system development.

d. Physics-based M&S

(1) Issue: Many M&S tools are based on empirical data rather than physical principles.

(2) Discussion: An important aspect of gaining acceptance of the output of M&S tools is to base them on proven principles of physics, validated by experimental data. The physics of many processes essential to DoD weapons systems are not yet adequately understood, e.g., secondary and tertiary effects of ballistic weapons impacting a target, synergistic effects, friction, and bending.

(3) Examples:

- TARDEC has needs for better representation of dirty environments such as mud, dust, and smoke.
- The physics of many ballistics events are not yet well understood, so M&S tools supporting live fire testing at TECOM are typically empirically-based.

e. Hardware and Software Limitations

(1) Issue: Limitations still exist with available hardware and software to support emerging requirements of M&S in the acquisition process.

(2) Discussion: Although the availability of significantly more powerful computer hardware and software have been drivers in the increased incorporation of M&S tools in the acquisition process, requirements continue to emerge for faster, larger, and more powerful support tools.

(3) Examples:

- NSSN Program Office (PO) workstations are not adequate for use with their large, dynamic databases which need more than 2 gigabytes of RAM. They also note that software developers are focusing on updates to workstation applications instead of mainframe

applications, because of the significantly larger market. This may result in future computational limitations.

- Deneb Robotics, Inc. (major producer of 3D graphics-based simulation) has developed for Electric Boat Company what they claim is the world's largest virtual prototype model. It has one million polygons and requires two gigabytes of RAM.

f. <u>Variable Resolution</u>

(1) Issue: Consistent system data descriptions are needed for both high and low resolution M&S tools.

(2) Discussion: Typical engineering level M&S tools are very high resolution, and CAD descriptions of systems and subsystems are developed to provide needed data. Many dynamic performance models may only accommodate a lower level of resolution thus causing loss of fidelity and attributes of the original CAD developed model which could skew final results. Force structure and affordability analyses may require very low level data resolution. In all cases, the representation, at both higher and lower resolutions, needs to remain consistent.

(3) Examples:

- SC-21 Program has requirements for system data to support varying resolution M&S.
- TARDEC has requirements for system data to support varying resolution M&S.

2. Cultural

a. <u>Acquisition Processes</u>

(1) Issue: New processes are required to realize the full benefits of using M&S tools in the total acquisition process.

(2) Discussion: Optimal use of M&S tools require the development of new processes with a culture of teamwork and openness.

(3) Examples:

- AFFTC Edwards has experienced program managers wanting a "fly-fix-fly" approach instead of a "predict-test-compare" approach which they believe is more cost effective.
- Deneb Robotics cautions its potential customers not to buy their software unless they are committed to changing the way they do business toward a genuine IPT approach. They stress that organizational leaders must emphasize change, department heads must become coaches, and new approaches must be developed to maintain core competencies that will be matrixed to tasks.

• TARDEC notes that current engineering practices are still based on "old" rules-of-thumb which were developed over many years. The value of these practices needs to be retained, but adapted to new ways of doing business.

• The automobile industry experiences resistance to change from smaller suppliers who cannot afford the M&S tools or training required with the new processes.

b. Incentives for M&S Use

(1) Issue: The use of M&S tools and processes is not appropriately incentivized.

(2) Discussion: Incentives for a DoD weapons system PM are tied to an old acquisition process. This process is designed to stop problems and failures that are not nearly as relevant in today's environment. Although almost every aspect of the acquisition process is undergoing change, and new M&S tools and processes are now available to support better quality at a lower cost, the incentives for necessary up-front investments in technology and infrastructure are not yet present.

(3) Examples:

• Many PM offices have Initial Product Testing as an early goal which stimulates funding release for production and fielding. Up front time and funding invested in M&S tools and processes for a better product or lower risk is perceived as detracting from their incentive for early fielding.

• AFFTC Edwards experiences some programs that don't accept the value of M&S tools and "drive the program pace" by schedule, cost, or similar pressures.

c. M&S Workforce

(1) Issue: Availability of trained personnel to support the development and use of M&S tools and processes.

(2) Discussion: In an era of significant Government downsizing, it is typical for the more recently hired employees to be the first to depart. In the fields of computer hardware and software use and development, it is these more recently educated workers who possess the skills and education required to implement and operate the technology. In addition to the pressures to down size, these same workers are in demand by private industry. There are concerns about the availability of adequate numbers of trained personnel in Government agencies and acquisition program offices to support the development and use of M&S tools and processes.

(3) Examples:

• TARDEC suggests that individuals or organizations which use an M&S tool should be "validated" on their understanding of that tool before results are accepted.

• AEDC is experiencing difficulty attracting and retaining staff in many areas requiring skill and experience in the use of emerging M&S tools and processes.

- Smaller contractors supporting DoD and the automobile industry have problems training personnel to operate the newer M&S tools and processes.

d. Acceptance of M&S

(1) Issue: The decision of how and in what way to use M&S tools and processes is often based on inadequate knowledge and experience.

(2) Discussion: The use of M&S tools and processes is often a function of the experience and personality of the key program decision makers. Their level of familiarity and comfort with these newer approaches is a major determinant in decisions to take advantage of these tools.

(3) Examples:
- AFFTC Edwards, NAWCWPNS China Lake, and TARDEC report similar experiences in the inconsistent acceptance of M&S tools and processes by different program offices.

3. Managerial

a. OSD and Service Guidance

(1) Issue: OSD and Service guidance fails to adequately encourage use of M&S tools and processes in support of the acquisition process.

(2) Discussion: Although the DoD acquisition process is moving towards less mandatory direction and requirements, there is a lack of knowledge and experience in how to leverage the opportunities presented by M&S tools and processes to produce a better weapon system within schedule and cost. OSD and Service guidance which helps the understanding of how and when to incorporate these tools would produce significant dividends.

(3) Examples:
- There is very little guidance in DSMC on availability of tools, and how program managers can capitalize on their investments.
- The Army requires program managers to submit an SSP for ACAT I and II programs. Even with specific guidance, this has been perceived as another bureaucratic requirement.

b. Ownership of Data

(1) Issue: Lack of Government rights to system data and open access to M&S tools used by a contractor, limits the usefulness and value of M&S in support of the process.

(2) Discussion: This remains a serious issue limiting the effectiveness of M&S tools and processes. This research project has not focused specifically on this issue to

determine its scope, but frequent cases were identified to the study team for both currently fielded weapons systems as well as those under development where this lack of full access to system data descriptions is a hindrance to effective use of M&S in support of the program. Data rights are a significant issue in the negotiations for a development contract for many reasons other than M&S use, but it should be recognized that the requirement for reusability of that data by other M&S tools is a significant element in the success of the program.

(3) Examples:

- AFFTC Edwards experiences situations where the contractor considers the model proprietary and not available to the Government.
- Sikorsky builds and owns simulations used on Comanche and other programs which are not available to the Government.
- Javelin program has experienced concerns about proprietary data and models. Contractors have been encouraged to build their own tools which then become proprietary.
- Mr. Coyle, DOT&E, and many others in DoD have suggested requiring a system model as part of the submission with a competitive proposal. TACOM has used this approach to a limited degree, but legal obstacles have severely restricted the process. Comanche Program Office used "fly-offs" between simulators as part of their Demonstration and Validation (DEMVAL) award evaluation.

c. VV&A Requirements

(1) Issue: The product of M&S tools must have credibility throughout the acquisition process.

(2) Discussion: M&S tools have little value in the acquisition process if their contribution is not accepted, but the verification and validation (V&V) process leading to accreditation is expensive and not well understood.

(3) Examples:

- TARDEC is struggling with how to fund needed V&V activities of M&S tools which are needed for use by many programs. Individual programs, many of which are small, are reluctant to carry the burden of funding an activity needed by other programs.
- AEDC experienced unclear guidance and mixed acceptance of their V&V activities from Service agencies using their analyses.

d. Funding Process

(1) Issue: There is no process to determine appropriate investment in M&S tools and processes for acquisition programs.

(2) Discussion: Funding for M&S tools and processes is embedded in total program funding and not separately identified. Thus, each program faces issues of the level of investment in these tools and processes as a tradeoff with other possible investments or expenditures within the program.

(3) Examples:

- AFFTC Edwards is often not able to update models with live test data at the completion of testing because of lack of funding or schedule demands.
- TARDEC is struggling with the reluctance and inability of individual Army program managers to make up-front M&S investments.

e. Use of System Models

(1) Issue: There is no control mechanism or agency to insure authoritative system models are used by those outside of the system program office.

(2) Discussion: The general availability of system models allows other programs or organizations to misuse that data to support programmatic claims or decisions detrimental to the original system. This situation causes program offices to overly control access to their system models to avoid misuse.

(3) Examples:

- TOMAHAWK Program Office reports use of unauthorized representations of their system model by outside organizations.
- Multiple Launch Rocket System (MLRS) claimed that representations of their system were not blessed by the Program Office when played in higher level models.
- Navy PEOs have expressed concern about a Navy initiative to represent their systems in a common frame of reference which would make them subject to 'trade-off' analyses.

C. Opportunities

Industry and Government have similar interests and are cooperating closely in many areas pertaining to M&S and streamlined acquisition. In reaction to global or national competition and other pressures, many firms have modified their approach to product development, manufacturing, and support. In many cases they are using M&S tools and processes extensively. Many of these firms have influenced the evolution of DoD acquisition policy, especially firms that are DoD contractors, and are forging closer alliances through teamwork and IPT/IPPD initiatives. Most large system contractors (such as those that bid for DoD ship, aircraft, tactical vehicle, and similar contracts) cannot afford mistakes during development, thus rely increasingly on the advantages provided by M&S.

The result is an increase in number and influence of various consortia, cooperative research and development agreements (CRDAs), and dual-use efforts. These trends lead to greater cooperation and efficiency.

An example is the National Coordinating Office for High Performance Computing and Communications (HPCC). Under the HPCC umbrella is the Army High Performance Computing Research Center (AHPCRC). This organization, in conjunction with the Army Research Lab (ARL), is undergoing a transformation to a concept known as the 'federated

laboratory' which has promise to make ARL more efficient. "DoD policy is to use commercial technology wherever possible, to out-source even technology base work, when the private sector has the lead in the technology, and to develop technology such that it is suitable for both military and civilian applications - dual use - thereby obtaining economies of scale."

Several methods for conducting joint business are being institutionalized. They include cooperative agreements, independent research and development (IR&D), and various methods of domestic technology transfer such as CRDAs and PLAs (Patent Licensing Agreements). These will allow new working arrangements while minimizing the contractual burdens on both parties. Another new thrust is the routine exchange of scientists and engineers between industry and Government.

Following are descriptions of opportunities in developing and improving simulation based acquisition by various programs and consortia formed to jointly address common issues in this area.

1. DARPA's Simulation Based Design (SBD)

DARPA plays a leading role in a number of M&S programs. A key project is SBD which was initiated in March 1993. The goal of the project is to 'revolutionize the Acquisition Process for complex military and commercial products' using distributed, collaborative virtual development environments. SBD is multifaceted in that it looks at all aspects of the system acquisition process, from mission analysis, through design and logistics considerations, to manufacturing and cost/risk analysis phases. The underlying belief is that M&S can improve time and cost for all areas of the acquisition process.

Phase I of the program has been completed. As ships are complex and costly systems, a ship hull/mechanics/electrical problem was selected for use in Phase I. The challenge was to design and build a roll-on/roll-off ship that could transit a given distance faster than current ships. First, from a catalog of 'product models' it was demonstrated that a user could select a new synthetic engine product model and introduce it into a 3-D CAD model of the ship. Through associativity, the CAD model identified 'fouls.' An example of a foul might be that the cooling capacity is insufficient for the new engine. The designer could then find a product model of a new cooler, and select and 'install' it into the ship model. Another foul might be that space is insufficient. Using virtual immersion, the designer is permitted to move walls and explore the impact of the moves. For each alteration, a manufacturing analysis model is used to make modifications needed to the sequence in which the ship is to be assembled.

Phase II of the project, a $20M a year program, is currently underway. The contractor team is headed by Lockheed and includes Boeing, General Dynamics, and Newport News Shipbuilding. This project will test SBD as a basis of simulation based acquisition. Their initial test is scheduled for February 1997.

2. Other DARPA Programs

The MADE (Manufacturing Automation and Design Engineering) program has as its long-term objective the development, integration, and demonstration of enabling technologies for design of complex electro-mechanical systems that will lead to affordable insertion of technology for force modernization. The technical approach is to leverage existing infrastructure using the WWW as the integration substrate, and to develop tools that incorporate downstream concerns into early design-stage consideration. MADE includes a team of major contractors including industry, tool vendors, and universities. It is a four-year, $47M effort. The program is divided into the following four areas: design representation and conceptual design, integration architectures and multi-disciplinary optimization, design exploration, and designer's interfacing. Expected program benefits include computer-based engineering tools to enable geographically distributed teams to meet DoD IPPD requirements.

The AM3 (Affordable Multi-Missile Manufacturing) is funded by DARPA for approximately $100M over five years. The goal is to develop and demonstrate innovative system concepts, and design, manufacturing and business practices that can substantially reduce the cost of the various DoD missiles and smart munitions. Some concepts being pursued by AM3 for cost reduction include: multi-missile component technology, IPPD process and tools, flexible manufacturing systems, enterprise electronic infrastructure, and streamlined business practices.

The goal of the RASSP (Rapid Prototyping of Application Specific Signal Processors) program is to dramatically improve the design process for complex digital systems. RASSP is a $150M DARPA/Tri-Service initiative that started about two years ago and has already implemented the first RASSP system which represents a significant advance over today's state-of-the-art. A key objective is to reduce the total product development time by a factor of four or greater, while improving product quality and reducing life cycle cost. Other goals are to field state-of-the-art products at system build time, and permit rapid upgrade to the system throughout its life cycle. RASSP is meeting its goals through a combination of advanced design methods that emphasize virtual prototyping, concurrent engineering, and design reuse; modular, scaleable signal processor architectures; and a comprehensive support base of electronic design infrastructure. The infrastructure includes recent updates to standards, automation tools, and enterprise integration capabilities, and hardware and software libraries. The program also adopted the incremental refinement, or 'model year,' design process in order to achieve short development schedules (3 to 12 months), continuous improvement, and to avoid point design solutions.

DARPA is associated with a wide range of programs intended to improve manufacturing effectiveness. Four major DARPA/DoD initiatives are: the Scaleable Flexible Manufacturing Program that focuses on electronics, materials, and information systems; Technology for Affordability program; Technology Reinvestment Program (TRP); and Manufacturing Science and Technology (ManTech) Program.

The ManTech program is closely associated with the Manufacturing Technology Information Analysis Center (MTIAC), one of a series of organizations chartered by DoD to facilitate use of existing scientific and technical information. MTIAC has a range of research interests relevant to this study, such as Electronics Processing and Fabrication, Manufacturing and Engineering Systems (includes MADE), Advanced Industrial Practices (includes AM3 program), and Metals Processing and Fabrication. The ManTech investment strategy is to apply small investments in selected areas in order to leverage the billions of dollars that commercial industry is investing to excel in world-class competition. Many of the best methods, processes, and capabilities can be adopted to develop and produce military products. The ManTech focus is on technology demonstrations and technology development. Examples of current ManTech demonstration programs include:

- Military avionics from an automotive production line (50% cost savings)
- Military aircraft structure using commercial practices and processes (50% cost reduction)
- Cost and cycle time reductions for machining precision aspherical optical lenses (30-50% reductions)
- Integrated scheduling throughout a mechanical product supply chain by adapting commercial tools (90% reduction in reschedule time)

3. ADPA's Study on the Application of M&S to the Acquisition of Major Weapons Systems

Industry is motivated to find ways to improve the acquisition process, including use of M&S. An example is the American Defense Preparedness Association (ADPA) study on the application of M&S to the acquisition of major weapons systems. The objective was to present the defense industry's viewpoint on using M&S to significantly reduce cost over the entire acquisition cycle of major weapons systems. The study was sponsored by the Assistant Secretary of the Navy (RDA) and the team included representatives from 13 major corporations and six government or university labs.

The current M&S environment is characterized as using specialized tools with limited scope and scalability, and with little interoperability. There are many independent databases with ad hoc configuration management and traceability. Initial process modeling tools are not widely employed so that the many advantages associated with early evaluation are not realized.

The study's vision for future M&S employment has as its foundation an integrated M&S environment and an iterative process. All stages of the acquisition process interact with the common product data repository. This permits use of a comprehensive multi-domain product model definition, which extends from operational need to downstream O&S activities as well as system modification and upgrade. A distributed object-oriented design database can also provide users with transparent hypermedia style access and seamless integration of all critical engineering disciplines. An iterative spiraling process permits rapid evaluation of multiple options, while using electronic exchange of system models to speed up information flow. This facilitates integrated process teams that span government and industry organizations.

The technical payoffs or advantages of using this approach include: quick impact assessment for changes in requirements, rapid evaluation of multiple design options, opportunity to manage technology insertion, more efficient understanding and communication of design data, streamlined integration and testing, a basis for reuse and re-engineering of existing designs, and better government and industry accountability. The team's draft conclusions were that this approach can dramatically reduce cost and schedule while improving product quality. The study goal is to achieve a 50% or 5 year (for large programs) time reduction to IOC for most programs (depending on types of learning curves).

4. DoD Manufacturing Initiatives

The DoD has a number of initiatives for flexible, computer-integrated manufacturing (CIM). The Navy Rapid Acquisition of Manufactured Parts (RAMP) Program is developing software and hardware modules for improving manufacturing engineering and production management. RAMP modules are operational in 12 Navy and Army facilities. The Army Flexible CIM (FCIM) program (an offshoot of RAMP) focused on establishing electronic links between inventory management and design engineering sites and on strengthening the analytical capability of these sites.

FCIM involves application of computers and related technologies to rapidly design, develop, produce, and maintain Army products, primarily component parts. Program goals are to provide a smooth and efficient process for modifying designs and producing parts in both low and high volumes with significantly decreased overall acquisition time, lower cost, lower inventory levels, and higher quality.

The Army Materiel Command's (AMC) Tobyhanna Army Depot is the lead on this DARPA funded program. AMC works closely with the University of Iowa, Lehigh University, and a consortia of companies on FCIM, as well as assisting with implementation of RAMP.

CAD/CAM tools and environment to be used in conjunction with FCIM are to be compatible with PDES/STEP (Product Data Model using STEP/International Standards for the Exchange of Product Data) and with DARPA's Initiative for Concurrent Engineering (DICE) network. M&S programs being used for factory automation include WITNESS and VERT. The FCIM goal is to cut existing procurement lead time from 500 to 30 days by improvements in equipment, communications, people, software, and business practices.

FCIM is a network of modules that link inventory control, configuration management, manufacturing/contractor sites. The overall strategy is to link appropriate enterprise elements and information requirements by using existing and developing technology. For the Electronics Module, results include a 66% reduction in cycle time, $3M in hard dollar cost savings, $3.8M in cost avoidance, improved communications between sites and customers, and improved re-engineering and reverse engineering for communication end items.

The FCIM program's benefits are being disseminated to other AMC sites and industry, including use of innovative concepts such as teaching factories, contractor implementation programs, and networks. FCIM seeks joint interaction and harmonization with other programs, including:

- Joint Computer-Aided Acquisition and Logistic Support (JCALS),
- Joint Engineering Data Management Information Control System (JEDMICS),
- Configuration Management Information System (CMIS),
- Automated Document Conversion System (ADCS), and
- Product Definition Standard System (PDSS).

5. National Information Infrastructure (NII) Manufacturing Report

Many organizations and individuals are working to improve the NII. An improved infrastructure will provide benefits in many areas, including manufacturing. A recent paper, "Manufacturing and the NII", provides good insights on trends, benefits, and requirements for future improvement. The potential benefits of NII include: ability to efficiently and quickly move data within and between organizations allowing collaboration among entities at distributed locations; enabling rapid vertical and horizontal integration of products and companies; accelerating first time optimization of products from design to production; and permitting virtual M&S, testing, and manufacturing.

> One study found that advanced manufacturing techniques that enable the rapid exchange of information not only increase quality and cut the number of design changes by 50%, but also reduce total cost by 30 to 60%, development time by 35 to 60%, design and product defects by 30 to 80%, and scrap work by 58 to 75%.

The report describes many innovations and improvements that are being employed by other major corporations, including ways to improve the national information infrastructure. Many of the initiatives are led by consortia. Examples of key consortia and initiatives related to manufacturing include:

- Manufacturing Extension Partnership (MEP) sponsored by NIST whose major efforts include LINKS (an information infrastructure program) and TECNet (a LINKS pilot program to connect extension centers and users with key data sources)

- National Industrial Information Infrastructures Protocols (NIIIP) Consortium led by IBM, is partially sponsored by the TRP, which is developing computer protocols, software architecture, tools, etc., for linking together virtual firms

- Rapid Response Manufacturing (RRM) Consortium made up of 4 large US manufacturers, GM, Ford, Texas Instruments, and United Technologies, with the intent of creating tools that "better assure an accurate first part, achieve one-pass product designs ... and provide simultaneous consideration of manufacturing process constraints in the generation of initial designs"

- National Initiative for Product Data Exchange (NIPDE), a partnership to coordinate the development of STEP through use of an approved standards development plan, hosted by NIST/DoC

- PDES, Inc., is a joint industry/government consortium to speed the development and implementation of STEP and which is comprised of various groups and programs including a demonstration project for Advanced Weapons System development

- Continuous Acquisition and Life-Cycle Support (CALS) is a joint government-industry initiative with the goal of allowing all parts of an enterprise to operate from a common digital database, in real time, for all life-cycle phases

- Systems Integration for Manufacturing Applications (SIMA) is a NIST program to develop a set of integrated manufacturing systems using High Performance and Communication (HPCC) technology with the goal of creating an Advanced Manufacturing System and Networking Testbed (AMSANT)

- Technologies Enabling Agile Manufacturing (TEAM) project by DoE helps industry collaborate with and use DOEs capabilities in key manufacturing thrust areas

- Agile Manufacturing Initiative is a DARPA and NSF program to develop the prototype information infrastructure that enables 'virtual companies' to be formed for design and manufacturing

Significant barriers including technical, cultural, and financial, exist to advanced manufacturing through use of an NII. Inexperience with information technologies and the perceived threat of new systems versus traditional ways of doing business is a barrier that must be overcome by the application of proper training and education. Uncertainty and risk associated with new models and infrastructure is a problem to be addressed. Selecting and configuring new information equipment to upgrade, replace, or use in conjunction with old equipment offers technical challenges. The report provides data showing that rates for adopting and investing in technology is a traditional problem for the US when compared to economic competitors. This is summarized in the following statements:

> ... most of the 370,000 small- and medium-sized manufacturers in the US, who comprise nearly 98% of all manufacturing firms, have neither the expertise, time, nor resources to modernize their manufacturing processes without some assistance. Moreover, small and large firms alike are inhibited by the difficulty they find identifying and understanding technology trends, generating adequate investment decision-making and strategic planning models, implementing new technologies and migrating from old legacy systems.
>
> ...the result of these trends is that, for the most part, where information technologies have been developed and applied to manufacturing operations, it has been done with a high degree of sophistication yet with a narrow focus that makes integration of these manufacturing technologies not economically feasible. As a result, while US manufacturers excel in product R&D and innovation and the automation of individual components of the overall manufacturing process, they frequently fare less well in the combination of individual technologies into an integrated manufacturing system, embodying such concepts as concurrent engineering, total quality management, and just-in-time inventory control.

6. Center of Excellence (COE) for Best Manufacturing Practices (BMP)

The COE for BMP provides a range of tools to assist program managers in all aspects of the manufacturing process, from design through production. The COE for BMP is sponsored by DoN and Department of Commerce and is available to assist any manufacturing organization that seeks to improve its practices. Many large defense contractors are participants in the organization and make use of the BMPs. The tools include:

- KnowHow, a knowledge database of acquisition regulatory guidance
- SpecRite, a knowledge database that allows specification generation
- TRIMS, a tool providing insight to the systems engineering process as well as risk assessment and review
- BMP Database, an experience database of best practices that have been verified and which include POCs for further assistance
- BMPnet, a communications system

KnowHow is a key tool providing guidance and compliance information necessary for acquisition programs. It can be used as a learning tool for new personnel, and it can serve as a search engine to determine specific information. TRIMS and SpecRite are management tools. Several success stories from the program are available.

The BMP Database documents best practices for issues related to the entire manufacturing process. The best practices are determined through visits and surveys to manufacturing sites by a team of experts in the necessary disciplines or functions. A report is published, with key observations divided into two categories: best practices and information. Best practices are those methods recognized as most successful and competitive within an industry, such that other firms may want to use them as benchmarks and emulate them. In general, proprietary data is not included in the report or the database, but may be obtained through the POC.

The BMPnet helps to disseminate important information to rapidly reach a wide audience. In summary, the COE for BMP helps keep US manufacturing companies and other firms highly competitive through sharing of the best manufacturing ideas and methods.

7. Joint Advanced Distributed Simulation (JADS)

The goal of this DoD program is to explore and increase the utility of advanced distributed simulation (ADS) for T&E of complex military systems such as aircraft, missiles, etc. JADS was chartered in October 1994 by OSD to investigate the use of ADS for both developmental and operational T&E. The program is investigating the utility of ADS including critical constraints and concerns, and requirements that must be met by an ADS system to support a more complete T&E capability in the future.

JADS testing concentrates on the performance of ADS and its components, not on any particular system. Data gathering and conclusions will focus on network performance,

relationships between data latencies, and ADS induced data anomalies. Testing areas have been selected to allow comparison of time, cost, complexity, and validity/credibility of data, as well as test activities that would be infeasible without use of ADS technology.

The key issue pertaining to the utility of ADS for T&E is determining the cost/benefits and the value added. Another issue pertains to critical constraints and methodologies for using ADS. JADS will research concerns such as simulation identification and capability evaluation, integration of varied models, interface and network development, support infrastructure, and verification and validation of networks. A third issue is what requirements are needed for ADS to support a more complete T&E capability in the future in terms of network and simulation standards for data structures, security, fidelity, scalability, emission representations, and reactive terrain.

The program currently includes two approved tests: a System Integration Test and an end-to-end test. These tests are scheduled for completion in 1998. A third Electronic Warfare test is also being considered. These tests will not provide sufficient data for overall conclusions about the utility for ADS for the full spectrum of T&E, therefore information will also be taken from other test areas. The goal is to obtain hard analytical proof for difficult issues regarding ADS in testing.

ADS is a means to interface live, virtual, and constructive players so they can interact with each other on a common playing field. Protocols standardized by the Institute of Electronic and Electrical Engineers (IEEE) have helped make Distributed Interactive Simulation (DIS) a reality; however these protocols are not necessarily sufficient for T&E purposes. ADS uses similar concepts as DIS, but goes further to achieve the enhanced capabilities required for full fidelity T&E. ADS will be more conceptual and therefore more flexible. ADS may use the High Level Architecture (HLA) currently under development. ADS permits a central computer to control the simulation nodes, and allows a central server to maintain the environmental data base and provide it to other nodes on demand. Instead of use of Protocol Data Units (PDUs) required by DIS, ADS can use a more flexible implementation that sends an entity only that information which is required.

The potential for ADS to enhance T&E is significant. ADS can help in test planning by helping determine which field tests are most critical. Testers can design tests to address mission-level MOEs using direct measurement and end-to-end tests. Simulation can provide environments that are not possible to test in the field, and allows for complete post-test extrapolation to differing scenarios and test environments. Some specific issues and risks are:

- complexity in terms of scheduling networks, test assets, operators, etc.
- latency associated with geographic distribution of test assets
- interfacing and reacting problems between simulated and live players
- similar interface problems between terrain database and actual terrain
- added complexity in the VV&A of a network of models, versus single ones
- coordination problems with numerous participating organizations
- data management for distributed testing in terms of range ‘truth’ when using dissimilar ranges
- technological maturity of ADS, especially in terms of stringent realism requirements

- reliability associated with an infrastructure for ADS
- whether cost for distributed testing will be less than for traditional testing

8. TARDEC's Tracked Vehicle Work Station (TVWS)

TARDEC employs the virtual prototyping process to conduct early exploration and evaluation of new vehicle concepts without actually building a physical vehicle. The process lends itself to continuous user participation, including soldiers who will ultimately use the system in the field, as well as the developers (government-contractor team). Advanced computer simulation enables early evaluation of new concepts without actually building a prototype vehicle.

TARDEC employs the TVWS to facilitate concept exploration and evaluation. Engineers can select and assemble a concept tracked vehicle using appropriate parts from a CAD parts database. They then select appropriate test environments and conduct virtual testing. By reviewing test results using various techniques, the engineer can validate, refine, or discard the concept, quickly and inexpensively. The TVWS has available the necessary component parts, scenarios, test plans, and other related databases, as well as the supercomputing, animation, display, and other capabilities needed to evaluate the tracked vehicle concept.

The TVWS also facilitates progression to prototyping and design activities and to development and use of crew stations and motion simulators. TVWS capabilities can flesh out the 3-D virtual prototype so that the user can explore inside the vehicle and obtain valuable human-machine interface feedback. By interfacing with other constructive and virtual simulations, the user is able to 'fight' the vehicle and better understand and improve its design before hardware fabrication. Later, the design evolves into a crew station envelope or simulator, which at first is not realistic in terms of configuration, but which is realistic in terms of human-machine interfaces. The envelope can be used under static conditions, or dynamic conditions using motion-based simulators. The crew station envelope is connected via the Distributed Simulation Internet to enable users to evaluate the effect of the conceptual vehicle on tactics and force effectiveness.

9. Automotive Consortia

Closely associated with TARDEC and TACOM are a series of organizations of which the most key are the National Automotive Center (NAC), the Automotive Research Center (ARC), and the Industry/University Cooperative Research Center (I/UCRC) for Simulation and Design Optimization of Mechanical Systems. Each of these is partially funded by DoD, and attempts to further the state-of-the-art in terms of optimizing design and manufacture of vehicle systems.

The NAC's role is to forge closer integration between legacy systems and evolving infrastructure improvements. TARDEC seeks to leverage commercial developments and apply them to Government needs. The NAC is especially involved in helping define a standard technical architecture to achieve a more integrated M&S approach.

The ARC has the role of conducting R&D for improved automotive manufacturing, especially for flexible, agile modeling systems. They work with many types of M&S tools with the goal of achieving better tool performance and interoperability. Their five research areas are: vehicle terrain dynamics, vehicle hardware/human interface simulation, M&S of vehicle structures, advanced propulsion simulation, and system integration. The ARC uses an organizational structure called the Quad Concept to ensure that every project is represented by university students, university faculty, industry researchers, and Government scientists. This ensures that technology that is developed is in tune with industry and Government needs, and is available for practical implementation.

The I/UCRC group is located at the University of Iowa and has as its objective development and distribution of advanced analytical simulations. Sponsors include TACOM, NASA, and the National Science Foundation (NSF). A key tenet of the Center's research is that there is a need for an environment in which advanced CAD/CAM/CAE tools can be concurrently brought to bear in support of engineering developments that involve a broad range of disciplines. The Center helped develop the TVWS. Other basic and on-going technical objectives for the Center are: dynamic simulation, operator-in-the-loop simulation, dynamic stress and lifetime prediction, structural design sensitivity analysis and optimization, pilot and driver projects for operator-machine interactive simulations, driving simulators, and SBD for military system supportability and human factors.

10. NAVSEA's Smart Product Model (SPM)

The NAVSEA SPM permits exploration of various concepts or designs before beginning to downselect the best. This program relates to the DARPA simulation based design (SBD) concept. Most virtual activities are in the early stages of the acquisition process (i.e., concept exploration, prototyping and design); however, they clearly link up with all stages of the life cycle. The SPM encompasses all stages of the life cycle, including lesson learned from operational systems. The Navy process relies heavily on the IPPD team and on multiple iterations of virtual design, build, and test, prior to the actual bending of metal. The design and analysis are based on assessing a series of ship functionalities such as signature, vulnerability, seakeeping, and so forth.

Data from the various stages of the model and for the various functionalities are stored in a common repository (the Smart Product Model) for access by the range of system developers and other users. The SPM interacts with the virtual environment and 'supporting' functions including manufacturing, logistics, financial, program management, and operational assessment.

11. Lockheed Martin's Virtual Development Environment

Lockheed Martin is using the Air Vehicle Virtual Development Environment to fully exploit the value of virtual development. Industrial sectors moving most swiftly toward virtual prototyping (VP) (aircraft, heavy machinery, and automotive) are characterized by high investment costs for items such as tooling, need for prototype development, desire for reduced

cycle time in order to rapidly integrated technology and other improvements, and high product support and O&S cost. Their move toward increased use of M&S is fueled by expected improvements of 30 to 50% reduction in design cycle time and cost, 25 to 50% reduction in assembly time and cost, up to 25% reduction in tooling cost, 50% reduction in time-to-market, and other significant reduction in product support cost. Table IV-1 provides some types and indicators of savings and increased effectiveness.

Lockheed Martin uses M&S in conjunction with digital product and process definition. VP provides a vehicle to test concepts and designs prior to committing resources, evaluate new concepts, verify design integrity, and in many instances, eliminate the need for hardware mockups. VP is used for all stages, from design to production and support. The major elements of VP are CAD defined models and static or 'flythrough' evaluation models. The latter are used for detecting interference, mismatch, and tolerance problems, and to help with system support assessments and performance and analytical assessments in 'real' environments.

Lockheed Martin has developed an M&S process vision that includes product, manufacturing, and factory/enterprise functions. The process spans functions from requirements definition to fleet operations, and helps integrate product configuration/design, manufacturing concepts, tooling, factory flow, and factory/enterprise design. Frequent looping through the operations analysis step ensures that all aspects of the design are updated and continue to best meet the established requirements. A hierarchy of simulation capabilities are needed to support the development process. Levels of capability include integrated CAD systems, rule-based design support, accurate 3-D solid models/visualizations, and physics-based simulation. Key virtual development environment capabilities are used for both concept development and detailed development using many common tools and a common design database.

Physics-based simulations provide a first approximation of how the product will perform and how the processes (in terms of production, logistics and O&S support, etc.) will rate in terms of effectiveness. First, however, solid design capabilities are used to construct the virtual air system model in terms of systems engineering and meeting the integrated needs and requirements of the system. The rule based conceptual designs permit configuring the system and its subsystems; developing process and resource information relating to manufacturing and tooling; and providing preliminary cost assessments (increasingly important in the new acquisition environment) for all aspects of the program, including all areas relating to production, test, and deployment/operations. M&S also allows earlier and better visualization of the system as it will evolve. This is useful for management as it evaluates not only the product but also the tooling and factory requirements and the maintenance and support needs.

TABLE IV-1: IMPROVEMENT INDICATORS BASED ON USE OF M&S

Process Activity	M&S Capability	Potential Cost Savings	Affordability Impact
Design optimization	Use rule-based models to select low-cost Fab. Processes, and standard parts, toolings, and processes	• Reduced part and assy. cost • Reduced tool design cost • Reduced tooling rqmts.	Development Development Production
Part Design	• Solid modeling • Computer simulated assembly with 3-D interactive graphics	• Eliminate physical mock-ups at $30M each • 30-50% cost reduction in design/verification steps • 20-25% reduction in first article (and on) assy. cost	Development Development Production
Loads analysis for tooling	Finite element analysis coupled with manufacturing process simulations	Eliminate scrap and rework due to tool loadings and tolerance changes	Development & Production
Conceptual design optimization	IPD and analysis models for IR and RF signature, RF emission, aerodynamics, structure	• Reduction in design and analysis spans, cost, and rework • Reduction in number of physical tests/better test planning	Development Development
RM&S design	• Model and simulate support • Processes and designs for supportability evaluation: - Ergonomic - Removal/replacement paths	• Potential reduction in maintenance man-hours up to a factor of 3 • Eliminate mock-ups	Support Development
Loads analysis	• Use integrated CFD and structural analysis models to determine initial pressure loads • Use integrated structural analysis and Navy-unique loads criteria	• Reduced design span • Reduced wind tunnel testing	Development Development
Weapons carriage and separation certification	Use integrated CFD loads analysis (virtual wind tunnel) to verify carriage and separation	• Wind tunnel test time reduced or eliminated • Elimination of most carriage and separation of flight tests	Development Development
Capacity planning	Simulate and evaluate processes and costs for varying production rates	Achieve rate insensitive costs	Production
Production training	3-D visual simulation of manufacturing process	Flattened learning curves	Production
Manufacturing design and planning	Simulate NC programs to verify paths, interactions, interferences, in-feasible positions, mismatches, etc.	• Eliminate rework • Reduced development effort	Production Development
Tolerance and variability assessment	M&S design and tooling integration with tolerance build-ups (use SPC data with assembly simulations)	Assembly cost reduction	Production
Manufacturing design and planning	Model and simulate manufacturing processes and factor flow (production management) and enterprise operations	• Reduced inventory/WIP • Reduced factory span • Learning curve lowered, lower TI cost, greater efficiency	Production
Production planning and training	Ergonomic simulations of manufacturing processes	• Improved salary/lower overhead costs • Reduced crew loading rqmts.	Production
Manufacturing planning	Simulate part/tool mechanical and thermal interactions	• Reduced tooling and capital rqmts. • Elimination of scrap and rework	Production

V. FINDINGS AND RECOMMENDATIONS

This study set out to assess M&S effectiveness in the weapon systems acquisition process. The resounding results were that M&S was effective in reducing risk throughout the development cycle, improving system performance, and lowering total life cycle costs. The documented metrics revealed this. Most programs cited cost avoidance or resource conservation. Specific CAD/CAM/CAE tools provide synthetic representations of system components, the future system, and the production process. The integration of these tools and their integrated system database provide the IPTs the continuity to make optimal decisions while concurrently evaluating development. The benefits of using M&S parallel those of the IPPD itself. The improved decision making ability, along with optimal design, assembly, employment, and user involvement are a great improvement over the "traditional" acquisition process.

There is a recognized need for technology to be used by the acquisition community as it re-engineers itself into using a team-based approach. This message has been given by Secretary of Defense, Dr. Perry, Under Secretary of Defense for Acquisition & Technology, Dr. Kaminski, and others as the benefits reaped from shifting from a stovepipe process to Simulation Based Acquisition become more obvious.

Modeling and simulation tools and processes are being used efficiently and effectively in each of the Services. Examples of early and continuous interaction between users, developers, and testers are evident in several programs. The use of M&S and virtual environments to quickly examine the impact and results of decisions have formed the basis for better decision making. Risk is better managed through analysis of virtual mockups in virtual environments. There are many examples of reduction in cycle time and greater flexibility in decision making through the use of M&S.

There are several challenges that the study team identified that need resolution. The issue of proprietary data and models is a contentious one with many implications. This issue was raised by both Government and contractor personnel, at nearly every site, as a point for discussion. Some of the other identified challenges, such as security of data and availability of data descriptions, may be resolved as the acquisition community grows to more fully embrace the distributed environment.

The technical challenges identified are not beyond the capability of improving technology to resolve, although prudent investments or proper encouragement might well speed and enhance the usefulness of the technical solutions. Cultural and managerial issues are more difficult to overcome. They are often the by-product of current initiatives in the acquisition process. Simulation Based Acquisition will focus on alleviating some of these concerns.

The study team noted the following challenges:

Type	*Challenges*
Technical	***o Interoperability of M&S Tools*** ***o Availability of Data Descriptions*** ***o Security/Sensitivity of Data*** ***o Physics-based M&S*** ***o Hardware and Software Limitations*** ***o Variable Resolution***
Cultural	***o Acquisition Processes*** ***o Incentives for M&S Use*** ***o M&S Workforce*** ***o Acceptance of M&S***
Managerial	***o OSD and Service Guidance*** ***o Ownership of Data*** ***o VV&A Requirements*** ***o Funding Process*** ***o Use of System Models***

One challenge is how to institutionalize M&S into the acquisition process so that it is used productively in an integrated manner in weapon system acquisition. The culture is ready to accept the changes in the acquisition process. This is evidenced by the programs using M&S piecemeal throughout the Services. The difficulty lies in encouraging the program managers to use these tools more efficiently and plan use of M&S seamlessly throughout the life cycle.

The words are in place in DoD acquisition documents to support implementation of Simulation Based Acquisition, though there are some growing pains associated with implementation of this shift. For example, the Multiple Launch Rocket System program office submitted an Extended Range - MLRS Test and Evaluation Master Plan (TEMP), approved through the Army Staff, that was heavily supported by the results of simulation. The Office of the Director, Operational Test and Evaluation rejected the TEMP and directed that 36 more live rockets be fired than in the submitted plan. The issue is, to what degree can M&S replace or augment field tests? There is no universal answer, but the message received in part by the community is that the thought and guidance are there, but the implementation and acceptance are not.

<u>Recommendation</u>: An immediate action is to institutionalize the use of models and simulations and insure that the community is knowledgeable about the tools available. The Services and OSD need to provide more responsive guidance relative to the advent of better and more useful simulation tools. Dialogue is needed within the Services and between the Services and OSD to effect policy on standardization. Program managers must overcome the management and cultural challenges that present barriers to the effective use of available technology.

The study found that program managers and their staffs are not well informed on M&S tools and their use in acquisition. Many program managers have had very limited exposure to models and simulations and would benefit from a short block of instruction which would emphasize the successes other programs have experienced by using M&S. Defense Acquisition University has begun to alter the curriculum in order to make the students more aware of the impact of using current technology early in the acquisition process and throughout the life cycle of the program.

Recommendation: *Action is needed to provide focused information on the availability and capabilities, to include success stories, of M&S to weapon system acquisition managers.*

A frequently discussed topic in the study team's visits was the need for investment early in the program for the tools that would be useful throughout the life cycle. For programs such as the F-22 and the Comanche, there was no choice but to plan to invest early in M&S and plan their program around those investments. For many smaller programs the decision is more difficult. Guidance is very general and there is little incentive for program managers to commit their early program funds to technologies for which they don't see an immediate return. This is complicated by the fact that there are no funding lines specifically designated for investing in the simulations necessary to support the acquisition.

Investment in simulation facilities extends beyond the money invested by weapon system programs. The anechoic chambers at Edwards Air Force Base and Patuxent River Naval Air Station and the wind tunnel facility and computational fluid dynamics capabilities at Arnold Engineering Development Center are examples of these facilities. The Simulation Test Acceptance Facility (STAF) at Redstone Technical Test Center was funded by program managers, but is a facility that could be used with minor modification by other missile programs.

Recommendation: *To meet the challenge of institutionalizing the use of available technology, the Services must be committed to providing funds for modeling and simulation at the inception of the program. OSD and the Services should commit Science and Technology dollars to upgrade capabilities and facilities that could serve many weapon system acquisitions. Program managers should be encouraged to use these facilities and capabilities instead of contracting to have their own system specific facilities and tools built.*

There is currently no vehicle to get information on M&S capabilities and facilities to the programs that have the potential to utilize the assets. It would be useful to the program managers and to the Research and Development and Test and Evaluation activities to have a source for investigating M&S capabilities available within the Defense Acquisition community.

Recommendation: *Develop an information source such as an Internet web page which would list capabilities in design; tools available, programs that have used them, activities they can contact for further information, etc. The same capabilities could be listed for testing; e.g., who does computational fluid dynamics, which facilities have wind tunnels and anechoic*

chambers, have any programs proven out this technology with their systems? The web page could also be used to identify innovative approaches in manufacturing and note those using virtual manufacturing environments.

Industry and Government are cooperating closely in many areas pertaining to M&S and streamlined acquisition. In reaction to global or national competition and other pressures, many firms have modified their approach to product development, manufacturing, and support. Many of these firms, using M&S tools and processes extensively, have influenced the revolution in DoD acquisition, especially firms that are DoD contractors, and they are forging closer alliances through teamwork and IPT/IPPD initiatives.

One key effort is DARPA's Simulation Based Design (SBD) program. The goal of the project is to "revolutionize the Acquisition Process for complex military and commercial products" using distributed, collaborative virtual development environments. Another significant partnership is the collaboration of Industry, Academia, and the Government in the National Automotive Center in Detroit.

Recommendation: Opportunities to cooperate with Industry such as the DARPA Simulation Based Design programs should be encouraged and continued. There appears to be great potential in partnerships such as the National Automotive Center where both the Government and Industry benefit from investigating new technology. There should be incentives to pursue business relationships such as these in order to utilize developing technology more efficiently.

In summary: There is consistent evidence of M&S being used effectively throughout the acquisition process but not in an integrated manner across programs or functions within the acquisition process. This evidence has been collected from individual success stories, though the benefits are not readily quantifiable into a general standard. The key is in focusing on the integration of M&S applications, across acquisition programs and throughout the process, not in exploring the applications themselves. In the final analysis, M&S will continue to grow in usage, capability and total contribution to the acquisition process. The opportunity exists now for the DoD to effect Simulation Based Acquisition by focusing on providing the opportunities to facilitate the change.

APPENDIX A - GLOSSARY

3-D	Three dimensional
A&T	Acquisition and Technology
AAAV	Advanced Amphibious Assault Vehicle
ACAT	Acquisition Category
ACETEF	Air Combat Environment Test and Evaluation Facility
ADCS	Automated Document Conversion System
ADPA	American Defense Preparedness Association
ADS	Advanced Distributed Simulation
AEDC	Arnold Engineering Development Center (USAF RD&E Center)
AFATDS	Advanced Field Artillery Tactical Data System
AFB	Air Force Base
AFFTC	Air Force Flight Test Center
AHPCRC	Army High Performance Computing Research Center
ALSP	Aggregate Level Simulation Protocol
AM3	Affordable Multi-Missile Manufacturing
AMC	Army Materiel Command
AMRAAM	Advanced Medium Range Air-to-Air Missile
AMSAA	Army Materiel Systems Analysis Activity
AMSO	Army Modeling and Simulation Office
ANSI	American National Standards Institute
ARC	Automotive Research Center
ARL	Army Research Lab
ASHPC	Advanced Simulation and High Performance Computing
ASME	American Society of Mechanical Engineers
ASN	Assistant Secretary of the Navy
ASNE	American Society of Naval Engineers
ASW	Anti-Submarine Warfare
ATFMS	Acquisition Task Force on Modeling and Simulation
B	Billion
BFV	Bradley Fighting Vehicle
BMP	Best Manufacturing Practices
C2	Command and Control
C3I	Command, Control, Communications and Intelligence
C4	Command, Control, Communications and Computers
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAIV	Cost as an Independent Variable

CALS	Computer Aided Acquisition and Logistics Support
CAM	Computer-Aided Manufacturing
CASE	Computer Aided Software Engineering
CATIA	Computer Aided Three-Dimensional Interactive Application
CATT	Combined Arms Tactical Trainer
CCTT	Close Combat Tactical Trainer
CE	Concurrent Engineering
CFD	Computational Fluid Dynamics
CIM	Computer Integrated Manufacturing
CinC	Commander in Chief
CITIS	Contractor Integrated Technical Information Service
CMIS	Configuration Management Information System
COE	Center of Excellence
CORBA	Common Object Request Broker Architecture
COTS	Commercial Off-the-Shelf
CRDA	Cooperative Research and Development Agreement
DA	Department of the Army
DARPA	Defense Advance Research Projects Agency
DD, MSEE	Deputy Director, Models, Simulations, and Software Evaluation
DDR&E	Director, Defense Research and Engineering
DEMVAL	Demonstration and Validation (phase)
DICE	DARPA Initiative for Concurrent Engineering
DIS	Distributed Interactive Simulation
DISA	Defense Information Systems Agency
DMSO	Defense Modeling and Simulation Office
DoC	Department of Commerce
DoE	Department of Energy
DoD	Department of Defense
DoN	Department of the Navy
DOT&E	Director, Operational Test and Evaluation
DPA	Digital Pre-Assembly
DSB	Defense Science Board
DSI	Defense Simulation Internet
DSMC	Defense Systems Management College
DT&E	Developmental Test and Evaluation
DTSE&E	Director, Test, Systems Engineering, and Evaluation
EB	Electronic Battlefield
ECP	Engineering Change Proposal
EDS	Engineering Development Simulator
EMD	Engineering and Manufacturing Development
EOA	Early Operational Assessment
ETMO	Education, Training, and Military Operations
EW	Electronic Warfare

FDTE	Force Development Test and Evaluation
FCIM	Flexible Computer Integrated Manufacturing (Army program)
FIS	Firing Impulse Simulator (Army asset, APG, MD)
FY	Fiscal Year
GM	General Motors
GOTS	Government Off-the-Shelf
GPS	Global Positioning System
GWEF	Guided Weapons Evaluation Facility (facility at Eglin AFB)
HLA	High Level Architecture
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HPCC	High Performance Computing and Communications (program)
HQ	Headquarters
HTI	Horizontal Technology Integration
HWIL	Hardware-in-the-Loop
IDA	Institute for Defense Analysis
IEEE	Institute of Electronic and Electrical Engineers
IGES	Initial Graphics Exchange Specification
IOC	Initial Operational Capability
IPL	Integrated Priority List
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
IR	Infrared
IR&D	Independent Research and Development
ISO	International Standards Organization
IT	Information Technologies
IT&E	Integrated Test and Evaluation
I/UCRC	Industry/University Cooperative Research Center
JADS	Joint Advanced Distributed Simulation
JAST	Joint Advanced Strike Technology
JCALS	Joint Computer-Aided Acquisition and Logistics Support
JEDMICS	Joint Engineering Data Management Information Control System
JITC	Joint Interoperability Test Center
JMASS	Joint Modeling and Simulation System
JPO	Joint Program Office
JSF	Joint Strike Fighter
JSIMS	Joint Simulation System
JSOW	Joint Stand-Off Weapon
JSTARS	Joint Surveillance Target Attack Radar System
JSTEB	Joint Synthetic T&E Battlespace

KEP	Kinetic Energy Penetrator
LCC	Life Cycle Cost
LCT	Longbow Crew Trainer
LPD-17	Amphibious Transport Ship
M	Million
M&S	Modeling and Simulation
MADE	Manufacturing and Design Engineering (DARPA program)
ManTech	Manufacturing Science and Technology
MAVWEST	Multiplex Armaments, Visionics, Weapons and Electrical Systems Trainer
MEP	Mission Equipment Package
MICOM	Missile Command (Army)
MLRS	Multiple Launch Rocket System
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOO	Measure of Outcome
MOU	Memorandum of Understanding
MS&A	Modeling, Simulation and Analysis (USAF program)
MSBTF	Modeling and Simulation Benefits Task Force
MSRR	Modeling and Simulation Resource Repository
MTIAC	Manufacturing Technology Information Analysis Center
MTS	Moving Target Simulator (TECOM at APG)
NAC	National Automotive Center
NASA	National Aeronautics and Space Administration
NAVSEA	Naval Sea System Command
NAWCAD	Naval Air Warfare Center Aircraft Division
NAWCWPNS	Naval Air Warfare Center Weapons Division
NBC	Nuclear, Biological, and Chemical
NC	Numerical Control
NCSA	National Center for Supercomputing Applications
NIDDESC	Navy/Industry Digital Data Exchange Standards Committee
NII	National Information Infrastructure
NIST	National Institute for Standards and Technology
NLOS	Non Line of Sight
NSF	National Science Foundation
NSS	Naval Simulation System
NSSN	New Attack Submarine (also NAS) (Navy Program)
O&S	Operations and Support
OASA	Office of the Assistant Secretary of the Army
OOT	Object Oriented Technologies
OOTW	Operations Other Than War
ORD	Operational Requirements Document

OSD	Office of the Secretary of Defense
OT	Operational Test
OTA	Operational Test Agency
OT&E	Operational Test and Evaluation
PDES	Product Data Model Using STEP
PDSS	Product Definition Standard System
PDU	Protocol Data Unit
PEO	Program Executive Officer
P&L	Production and Logistics
PLA	Patent Licensing Agreement
PNGV	Partnership for the Next Generation Vehicle
PM	Program Manager
PO	Program Office
POC	Point of Contact
PPF	Platform Proto-Federation
PRIMES	Preflight Integration of Munitions and Electronic Systems
R&D	Research and Development
RAM	Random Access Memory
RAM	Reliability, Availability, and Maintainability
RAMP	Rapid Acquisition of Manufactured Parts (Navy program)
RASSP	Rapid Prototyping of Application Specific Signal Processors
RCS	Radar Cross Section
RDA	Research, Development and Acquisition
RDC	Research and Development Center
RD&E	Research, Development and Engineering
RDEC	Research, Development and Engineering Center
RDT&E	Research, Development, Test and Engineering
RF	Radio Frequency
RFP	Request for Proposal
ROI	Return on Investment
RTTC	Redstone Technical Test Center (Army)
SAIC	Science Applications International Corporation
SBA	Simulation Based Acquisition
SBD	Simulation Based Design
SC-21	Surface Combatant - 21st Century (Navy Program)
SDRC	Structural Dynamics Research Corporation
SEP	Simulation Endorsement Process
SIIRCM	Suite of Integrated Infra-Red Countermeasures
SIL	System Integration Laboratory
SIMCORE	Simulation Common Object Repository Environment
SIMNET	Simulation Network
SOW	Statement of Work

SPM	Smart Product Model
SSA	Software Support Activity
SSP	Simulation Support Plan
STAF	Simulation Test Acceptance Facility (at RTTC)
STEP	International Standard for the Exchange of Product Data
STRICOM	Simulation, Training and Integration Command
SWIL	Software in the Loop
T&E	Test and Evaluation
TACOM	Tank Automotive Command (Army)
TACTICS	Tri-Service Advanced Countermeasures and Threats Integrated Combat Simulation
TAMIP	Target Acquisition Model Improvement Program
TARDEC	Tank Automotive Research, Development and Engineering Center
TECOM	Test and Evaluation Command (Army)
TEMA	Test and Evaluation Management Activity (Army)
TEMP	Test and Evaluation Master Plan
TEMS	Test and Evaluation Mission Simulator
TILV	Target Interaction, Lethality and Vulnerability
TMS	Tactical Missile Signature (facility at AEDC)
TRP	Technology Reinvestment Program
TVWS	Tracked Vehicle Work Station
USD	Under Secretary of Defense
VISION	Visual Simulation and Organizational Network (Lockheed Martin program)
VM	Virtual Manufacturing
VNS	Virtual Notional Ship
VP	Virtual Prototyping
VPG	Virtual Proving Ground
VSWE	Virtual Ship Warfare Environment
VTF	Vibration Test Facility (TECOM, APG)
VTI	Vertical Technology Insertion
V&V	Verification and Validation
VV&A	Verification, Validation, and Accreditation
WAAM	Wide Area Anti-Armor Munitions
WBS	Work Breakdown Structure
WIP	Work in Progress
WSSF	Weapon Software Support Facility (Navy, China Lake, CA)
WWW	World Wide Web

APPENDIX B - BIBLIOGRAPHY

BOOKS AND REPORTS:

1. Acquisition Task Force on Modeling and Simulation, Final Report of the Acquisition Task Force on Modeling and Simulation, 17 June 1994.

2. Apache Attack Helicopter PMO, Simulation Support Plan for the AH-64D Longbow Apache, undated (approximately March 1995).

3. Arnold Engineering Development Center, DoD Integrated Test and Evaluation Successes Using Computing Resources, Arnold Air Force Base, April 1995.

4. Callero, Monti, et al. (Rand, National Defense Research Institute), Enhancing Weapon System Analysis: Issues and Procedures for Integrating a R&D Simulator with a Distributed Simulation Network, 1994.

5. Center of Excellence for Best Manufacturing Practices, Report of Survey Conducted at Lockheed Martin Tactical Aircraft Systems, Fort Worth, TX, August 1995.

6. Department of Defense, Under Secretary of Defense for Acquisition and Technology, Modeling and Simulation Master Plan (DoD 5000.59-P), Washington, DC, October, 1995.

7. Department of the Air Force, Functional Area Plan for Modeling and Simulation, HQ USAF/XOM, 1996.

8. Evans, LTC Thomas R. et al., Modernization in Lean Times: Modifications and Upgrades, DSMC, FT Belvoir, Va., July 1995.

9. Garcia, LTC(P) Albert B., et al., Virtual Prototyping: Concept to Production, DSMC, March 1994.

10. General Accounting Office, Military Training: Cost-Effective Development of Simulation Presents Significant Challenges: Report to Congressional Committees, GAO/NSIAD 96-44, Military Training, 8 November 1995.

11. Gentsch, Eric L., et al. (Logistics Management Institute), Department of Defense's Flexible, Computer-Aided Manufacturing Initiative, January 1996.

12. Harrison, Ben L. (MG USA, Ret.), Army Aviation Simulation Survey, July 1992.

13. Joint Directors of Laboratories Technology Sub-panel for Target Interaction, Lethality, and Vulnerability (TILV), DoD FY95 Master Plan for TILV Science and Technology (S&T) Programs, Volume I, Classical Ballistic Threats, 4 May 1995 (Revised).

14. Marks, Peter and Kathleen Riley, Aligning Technology for Best Business Results, Design Insight and Riley Associates, 1995.

15. Marti, Jed, et al. (Rand, National Defense Research Institute), SEMINT: Seamless Model Integration, 1995

16. Modeling and Simulation Benefits Task Force, Defense Modeling and Simulation Office, Modeling and Simulation Benefits Task Force Report Out to the Modeling and Simulation Working Group, 26 October 1995.

17. Moskwa, Deborah A., Virtual Prototyping on Army Land Systems (VPALS) Benefit Cost Study, Cost Analysis Division, US Army TACOM, August 1995.

18. NASA, Small Spacecraft Technology Workshop: Summary and Conclusions, and Technical Presentations, NASA Conference Pub 10125 and 10126, Sep 21 to 24, 1993.

19. National Institute of Standards and Technology, Dept. of Commerce, Proceedings of the Manufacturing Technology Needs and Issues: Establishing National Priorities and Strategies Conference, April 26-28, 1994, edited by Cheryl Albus and J. D. Meyer.

20. National Research Council, Live Fire Testing of the F-22, National Academy Press, Wash, D.C., 1995.

21. Naval Research Advisory Committee, Report on Modeling and Simulation, (NRAC 94-3), November 1994.

22. Pacheco, Joselito M. (ITT Research Institute), Rapid Prototyping, Manufacturing Technology Information Analysis Center, Report MTIAC SOAR-93-01, March 1993.

23. Piplani, COL Lalit K. et al., Systems Acquisition Manager's Guide for the Use of Models and Simulations, DSMC, September 1994.

24. Svedlow, Martin (TASC), TACTICS Vision and Overview, Reading, MA, 1 May 1995.

25. Transportation Research Institute, University of Michigan, Driving America's Renaissance: Human Resource Issues in Michigan's Automotive Industry, 1995.

26. US Army Missile Command, RD&E Center, Advanced Simulation Center Hardware-in-the-Loop Simulation Facilities at RD&E Center, USA MICOM, December 1992.

BRIEFINGS:

1. American Defense Preparedness Association (ADPA) briefing, "Status Report on ADPA Investigation into the Application of Modeling and Simulation to the Acquisition of Major Weapons Systems," 1 May 1996.

2. Billingsley, Dan W., briefing "Simulation Based Design Overview," for Design for Production Class, 22 March 1996.

3 Fallin, Dr. Herb, Briefing to the US Army Automotive Research Center, "Implications of the New Revolution in M&S," May 28, 1996.

4. Langhorst, LTC Rich, "RAH-66 Comanche Program Update", 23 February 1995.

5. Lockheed Martin, Tactical Aircraft Systems, briefing, "Modeling and Simulation Project: Air Vehicle Virtual Development Environment," March 14, 1996.

6. McBride, CDR Dennis K., PhD, Briefing for the Society for Computer Simulation "The Future: How to Get There From Here," July 25 1995.

7. McGlone, Stephen A., "Computer Aided Manufacturing (CIM) Overview," 10 April 1996.

8. Naval Air Systems Command, annotated briefing, "Collaborative Virtual Prototyping: An Assessment for the Common Support Aircraft Initiative," 24 October 1995.

9. NAVSEA briefing "Product Modeling for Naval Ships," 31 January 1996.

10. Renner, Ernie, "The Program Manager's Workstation," Course booklet, DSMC Course No. 192B, Rev. 3.2, undated.

11. Simmons, Martha (Sverdrup Technology, Inc./AEDC Group), "Modeling and Simulation Tools and Applications," 1995.

12. Smullen, J. R., "Air Combat Environment Test and Evaluation Facility," 1995.

13. TARDEC, TASC and National Automotive Center, "Evolution of the Acquisition Process Through TACTICS, SIMCORE, and VP," undated.

ARTICLES:

1. Barney, LT James R., and RADM Zerr, John J., USN, "NSSN - New Attack Submarine: US Navy's 'Paperless Submarine' Undergoes Exhaustive Early Operational Assessment," in Program Manager, March-April 1996, pp. 38 to 41.

2. Battershell, A. Lee, "Technology Approach: DoD versus Boeing, A Comparative Study," in Acquisition Review Quarterly, Summer 1995, pp. 213 to 230.

3. Beck, Dr. Ronald C., "Full-Scale Simulation," Army R, D, and A Bulletin, September-October, 1982, pp. 1 to 2.

4. Beck, Dr. Ronald C., and John C. Schmuhl, "Role of Simulation at the Army Tank-Automotive Command," Army R, D, and A Bulletin, March-April 1992, pp. 33 to 35.

5. Burt, John A., "Increasing Program Management Effectiveness Through Single Process Facilities," in Program Manager, March-April 1996, pp. 12 to 14.

6. Cancian, Mark, "Acquisition Reform: It's Not as Easy as It Seems," in Acquisition Review Quarterly, Summer 1995, pp. 189 to 198.

7. Case, Thomas R. (BG, USAF), "A New Vector: Air Force Modeling and Simulation," in Phalanx, Vol. 28, No. 3, September 1995, pp. 1, 13 to 16.

8. Childress, CWO Alan, USA, "A Customer-Led IPT Success Story," in Program Manager, May-June 1996, pp. 10 to 14.

9. Conrow, Edmund H., PhD, "Some Long-Term Issues and Impediments Affecting Military Systems Acquisition Reform," in Acquisition Review Quarterly, Summer 1995, pp. 199 to 212.

10. Cothran, Julian, "Battle Labs: Tools, Scope and Test Beds," in Acquisition Review Quarterly, VOL 3, No 1, Winter 1996, pp. 51 to 62.

11. Coyle, Philip, "PM Interviews Philip Coyle," in Program Manager, May-June 1996, James Whitmeyer, editor, pp. 2 to 8.

12. Douglass, John W., "Undersea Warfare: Balancing Affordability and Advanced Technology," in Sea Technology, January 1996, pp. 11 to 12.

13. Editorial, "Arsenal Ships Steaming Toward Budget Decision," in National Defense, April 1996, pp. 32 to 34.

14. Eichblatt, Emil J., Jr., "Use of Simulation to Evaluate Tactical Missile Performance," in ITEA Journal, September/October 1994, pp. 30-34.

15. Forst, John, unpublished document, "Development Cycle Database," and "IPD Tools Summary Package," undated.

16. Franklin, BG Peter C., "High-Tech Training," in International Defence and Security Development, 1996, pp. 48 to 50.

17. Grimes, Vincent P., "Redesigning the Institutional Army Means Radical Changes," in National Defense, April 1996, pp. 16 to 17

18. Grimes, Vincent P., "Army Leaders Close Ranks to Push Truck Acquisition," in National Defense, April 1996, pp. 18 to 19.

19. Hewill, Clyde, LtCol, USAF, "Getting to the On-Ramp of the Information Super-highway," in Acquisition Review Quarterly, VOL 3, No 1, Winter 1996, pp. 19 to 38.

20. Holinko, Dr. Myron, "Use of the Digital Integrated Lab for Force XXI," in Army RD&A, March-April 1996, pp. 9 to 12.

21. Jeska, COL Robert S., and Susan M. Erwin, "Blueprint for Army Acquisition Reform," in Army RD&A, March-April 1996, pp. 37 to 38.

22. Johnson, Collie J., "DoD Press Briefing Underscores Important Acquisition Reform Initiatives," in Program Manager, March-April 1996, pp. 6 to 11.

23. Journal of Electronic Defense, January 1996 Supplement, "A Sampling of Electronic Warfare Simulators," pp. 46, 52 to 53.

24. Kaminski, Dr. Paul G., "DoD's Fiscal 1997 Acquisition and Technology Program," in Defense Issues, Volume 11, Number 32.

25. Keck, Eric, "The Utility of Advanced Distributed Simulation to Test and Evaluation," in ITEA Journal, September/October 1994, pp. 24 to 29.

26. Kuntz, Dana, and Maren Smith, "US Designing a Clean and Mean Attack Submarine," in National Defense, April 1996, pp. 32 to 33.

27. Langford, Gilbert B., "Teaming for Integrated Product and Process Management," in Army RD&A, November-December 1995, pp. 7 to 10.

28. Longhouser, MG, John E., "Converting Computer Power Into Combat Power," in Army RD&A, March-April 1996, pp. 4 to 8.

29. Lopez, MAJ Steven and MAJ Fred Coppola, US Army, "Crusader: Force XXI's Top Gun," in Military Review, November-December 1995, pp. 63 to 68.

30. Machlis, Sharon, "How 'Swift Samples' Buy You Time," in Design News, February 21, 1994, pp. 66 to 70.

31. Manary, Joel M., "DSMC's CASA Model Still Going Strong," in Program Manager, January-February 1996, pp. 37 to 40.

32. Meadows, Sandra I., "Navy Spending Blueprint Props Advanced Weapons, Platforms," in National Defense, April 1996, p. 31.

33. Nagy, Chris et al., "Advanced Manufacturing and Packaging Technologies for Military and Commercial Markets," in Journal of Electronic Defense, January 1996 Supplement, pp. 84 to 86.

34. NASA/SRS Technologies Report, "IPT Tools Summary Package," undated.

35. Nordwall, Bruce D., "Simulation Improves USAF EW Hardware Testing," in Aviation Week & Space Technology, October 24, 1994, pp. 52 to 56.

36. Norton, William J., MAJ, USAF, "Striking a Balance: Balancing Modeling and Simulation with Flight Testing," in ITEA Journal, March-April 1996, pp. 34 to 40.

37. Palmer, Craig et al., "RASSP Cuts Development Time and Cost," in Electronic Engineering Times, July 17, 1995, p. 48.

38. Roche, Edward M., "Business Value of Electronic Commerce Over Interoperable Networks," in Information Infrastructure and Policy #4, 1995, pp. 307 to 325.

39. Roddy, COL Michael A., and Gerald S. Smith, "Javelin Innovations in Acquisition," in Army RD&A, March-April 1996, pp. 41 to 44.

40. Solomond, Dr. John P., and Dr. D. Ross Grable, "Software Support: Critical to the Army's Future," in Army RD&A, March-April 1996, pp. 13 to 16.

41. Treece, James B., "Making Samples in a Snap," in Business Week, June 19, 1995, pp. 128 to 129.

42. Wilson, John, "Battle Labs: What Are They, Where Are They Going?" in Acquisition Review Quarterly, VOL 3, No 1, Winter 1996, pp. 63 to 74.

43. Zittle, Randy C., "Virtual Prototyping: A Powerhouse for IPPD," in Proceedings on the International Council on Systems Engineering, July 1996.

CAPABILITY STATEMENTS, BROCHURES, AND WEB PAGES:

1. Army High Performance Computing Research Center (AHPCRC) Home Page (http://ww.arc.umn.edu/html/hpc), Bulletin and Information Papers, Summer 1995 to Spring 1996.

2. American National Standards Institute (ANSI) (http://www.scra.org/uspro), "Standards," undated.

3. Director of Test, Systems Engineering and Evaluation (DTSE&E) Home Page (http:// www.acq.osd.mil/ te/programs/msse.html), Organization and Programs, 10 May 1996.

4. DMSO Home Page (http://triton.dmso.mil/projects/hla/), "DoD High Level Architecture (HLA)," 20 May 1996

5. DoD Information Analysis Center (IAC) Hub Page, April 1996, including Manufacturing Technology IAC and Defense M&S and Tactical Technology IAC Home Page (http://dmsttiac.iitri.com/ms&t/index.htm), February 1996.

6. DTIC Acquisition Information Home Page, "HOV-LANE (Hypertext - Online-Virtual Library for Acquisition News and Electronic Information)", (http://www.dtic.mil/ hoflane), undated.

7. JAST WWW Home Page "JAST Virtual Manufacturing Fast Track, Demonstrated Benefits of Affordability Technology," (http://www.jast.mil/), March 1996.

8. Joint Advanced Distributed Simulation (JADS) Joint Test Force (JTF) 'The Gateway to Reality' (Home Page (http://www.jads.abq.com), 1996.

9. Manufacturing Technology Information Analysis Center (MTIAC) Home Page (http://dmsttiac.hq.iitri.com), and data search results, various titles, 1995 and 1996.

10. "Manufacturing and the NII, Draft for Public Comment," Home Page (http:// www.iitfcat.nist.gov:94/), 1994.

11. Navy Center of Excellence for Best Manufacturing Practices Home Page (http:// www.bmpcoe.org and http://www.acq-ref.navy.mil/center.html), "Charting a New Course," January and April 1996.

12. Office of the Assistant Secretary of Defense (Public Affairs) Home Page (http:// www.dtic.dla.mil/defenselink/news), "Defense Acquisition Programs Forecast Cost/ Schedule Savings of up to 50 Percent from Acquisiton Reform," 15 March 1996.

13. Paladin/FAASV Home Page "Paladin/FAASV Program Overview," (http://www. atc.army.mil/brochures/atirs.html), 1995.

14. Renner, Erni, “The Program Manager’s Workstation: An Expert System for Acquisition Management,” undated.

15. Samenario, Maria, “Lucent Fires Up Inferno in Net Software Quest,” in PC Week OnLine Home Page (http://pcweek.com/news), 7 May 1996.

16. SDRC’s News, MetaPhase Series 2, and I-DEAS Home Page (http://sdrc.com), several articles and press releases, 30 October 1995.

17. University of Iowa, Center for Simulation and Design Optimization of Mechanical Systems, fact sheet, undated.

18. University of Iowa, Center for Simulation and Design Optimization, “Advanced Military Vehicle Simulation System (1994 -6th year).”

19. University of Iowa, Center for Simulation and Design Optimization of Mechanical Systems, “Simulation Based Concurrent Engineering of Mechanical Systems,” undated.

20. US Air Force Acquisition Model Home Page (http://www.safaq.hq.af.mil), Various Bulletins and Briefings, May 6, 1996.

21. US Army STRICOM Home Page, “STRICOM Products and Services,” and “Army Simulation Policies,” (http://stricom.army.mil), 1996.

22. US Army TECOM and ATIRS & ADACS (Army Test Incident Reporting System and Automated Data Collection System) Home Page (http://www.atc.army.mil/, and /www.acq.osd.mil/api/asm), 20 May 1996.

23. US Joint Spectrum Center (JSC): A Guide to Capabilities and Services, undated.

24. US Product Data Association, ProNews Home Page (http://www.scra.org/pdesinc/news.html), “In STEP with Suppliers” and “The AEROSTEP Project,” March 1995.

APPENDIX C - SUMMARY OF RELATED STUDIES

Many previous studies and investigations have examined the use of M&S tools and methods in the acquisition process. Most studies pertain to evaluating the level of M&S use, or suggesting ways to increase the use and productivity of M&S. None has had as its focus the need to quantify the level to which M&S improves the acquisition process, the focus of this effort. Pertinent studies are summarized below, with emphasis on results that pertain to the objectives of this study.

TABLE C-1. Past Related Studies and Analyses

AUTHOR	TITLE	DATE
Army Science Board	1988 Summer Study, Army Testing	Feb '89
Army Science Board	1991 Summer Study, Army Simulation Strategy	Dec '91
Inst. for Def. Analysis (IDA)	Army Aviation Simulation Survey	Jul '92
Rand	Enhancing Weapon System Analysis	May '94
Army Science Board	1993 Summer Study, Innovative Acquisition Strategies for the 1990s	Jul '94
Acq. Task Force on M&S	Report Out of the Acquisition Task Force on M&S	Jun '94
IDA, Paper P-3062	Review of DMSO Projects/Activities for FY92-94	Aug '95
M&S Benefits Task Force	Report Out of the M&S Benefits Task Force	Dec '95

1. Army Science Board, "1988 Summer Study on Army Testing," February 1989, Office of the Assistant Secretary of the Army (RDA).

This study assessed the effectiveness of Army T&E. Of the six principal issues covered, two were of interest to this study: use of M&S in support of T&E; and, improvements in test facilities and resources. The most important finding was that M&S use was poorly coordinated. Another related point was that certain facilities required for future testing are not available. The study also dealt with test planning and implementation, test data, and how data is used in the decision-making process.

Most M&S used at the time of the study lacked integration and failed to encompass areas such as supportability, NBC protection, and EW. There was also a need to better validate M&S capabilities and to upgrade M&S based on field test results, lessons learned, and other sources of data. The study stated that M&S should be used for earlier identification of system problems. It should also provide a connecting link between phases of testing, and between test organizations.

Major barriers to the increased use of models and simulations, in addition to the technical challenges of their proper use, are (1) the need to overcome unfounded perceptions regarding their credibility and realism, and (2) that their use would increase T&E cost.

The study saw a need for better policy on use of M&S in the T&E process, in part to demonstrate its potential for improving the quality and reducing the resources required in testing. This includes the need for a single coordinating point, a supporting technology base, and appropriate training for Army professionals. M&S was found to have potential as a unifying framework for operator, logistics, and maintenance functions. Other advantages of using M&S are listed in Appendix B of the study, with references.

2. Army Science Board, "1991 Summer Study: Final Report on Army Simulation Strategy," December 1991, Office of the Assistant Secretary of the Army (RDA).

The study assessed the status of M&S technology with regard to: barriers, enhancement opportunities, payoffs and benefits, and its role in development and testing and in RD&A. The study found use of M&S to be widespread and important, and stated that use of the Electronic Battlefield (EB), as defined in the report (see figure C-1 for a depiction of the functions and opportunities of the EB), can revolutionize the Army's way of doing business while reducing cost and increasing quality.

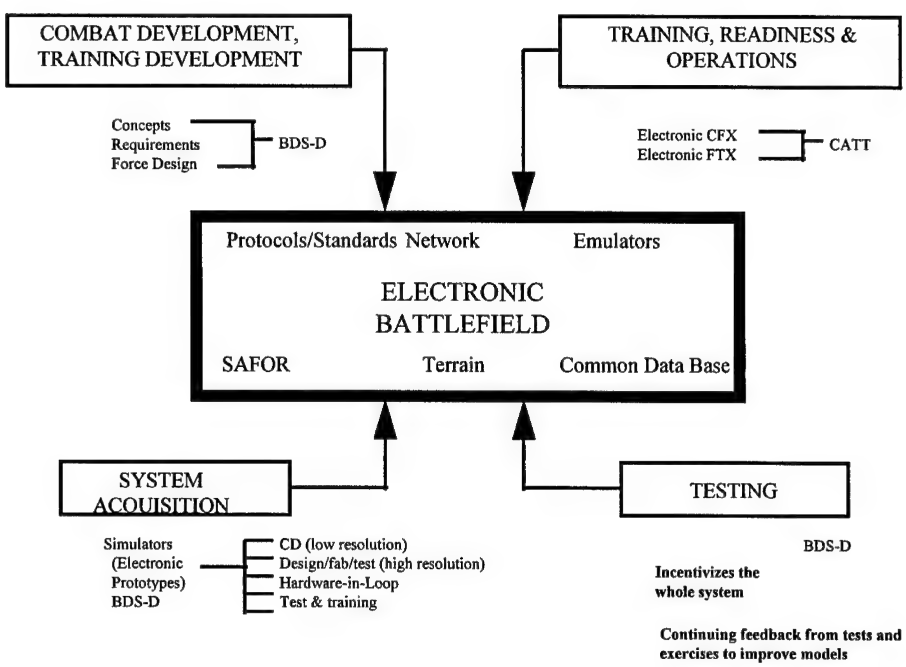

Figure C-1: Electronic Battlefield Functions and Opportunities

Simulation should be used for electronic prototypes through all phases of the force development and materiel acquisition processes. Use of early electronic prototyping will be invaluable in refining requirements, understanding how technology will fit with future systems, and help evolve physical prototypes. The full spectrum of capabilities are needed, from low resolution to high resolution and hardware-in-the-loop. "... for FDT&E and OT, electronic prototypes should be used both as a preview of all possible required physical tests and as an extension beyond physical testing capability." This will reduce the need for physical testing, but will in turn require a fundamental change in policy toward testing, one which will probably have to evolve over time as the EB proves itself.

The EB should serve as the primary test environment for early evaluation of operational utility. The quality and consistency of the data bases and models for the EB will be of paramount importance. Key models must be labeled 'certified' to show they are acceptable, while new products can be 'not certified' for introduction of new concepts for testing. Army resources must focus on specific Army needs, leaving R&D for underlying technology to others such as DARPA and the private sector.

3. IDA, "Army Aviation Simulation Survey," July 1992.

Conducted during a period of rapid technological change, this survey helped determine priorities for new capabilities in Army Aviation RD&A and related areas such as training. The report also describes the need for a more unified effort with regard to aviation related M&S. The report takes a broad view of the integration of M&S, including live forces on instrumented ranges and virtual and constructive war games. A large number of the survey responses/recommendations from 1992 have been acted upon already. The following areas pertinent to acquisition M&S (as well as for training applications in many cases) were cited as needing more attention:

- greater fidelity in battlefield representation,
- better networking of simulations/simulators,
- reconfigurable cockpits and mission equipment packages (MEPs),
- better ability to evaluate subsystems/MEPs relative to the total system,
- faster, smaller computational systems,
- better automated tools for building models, and
- ability to interface between high and low resolution simulators.

This survey was conducted at the time that technological advances were beginning to permit use of distributed interactive simulations capable of man-in-the-loop warfighting on futuristic battlefields. The report is intended to help determine priorities on where money should be spent for new and enhanced capabilities in the areas of conceptual design, performance analysis, testing, manufacturing process design and production, and training and mission rehearsal from crew to joint and coalition levels. Ten organizations were surveyed with the Aviation Center and the Aviation Systems Command submitting multiple reports. The report

summarizes the capabilities of Army simulation facilities relevant to Army aviation R&D, as well as major defense industry firms active in aviation R&D.

4. Rand (National Defense Research Institute), "Enhancing Weapon System Analysis: Issues and Procedures for Integrating an R&D Simulator with a Distributed Simulation Network," 1994.

A 1994 Rand study describes an important limitation of the current process -- the inability to evaluate high fidelity representations of developing systems in a realistic overall combat environment. It offers a proposal for using simulation and networking to evaluate systems and resolve deficiencies in current weapons system analysis methods. The proposal is to combine high fidelity representations of developing systems with the combat simulation environment of SIMNET. In this way, it is possible to:

- simulate a system's specifications/capabilities in sufficient detail to measure performance differences in alternative approaches or technologies,
- simulate the system's performance in the military unit configuration and operational environment for which it is being developed, and
- have humans operating the system in the intended combat environment and making real-time decision.

Such an approach can overcome the drawbacks associated with use of professional judgment, combat simulation, R&D human-operated simulators, and prototypes in live T&E. Each of these tools are currently used in the traditional process, and are useful, but are not able to achieve the combined abilities outlined in the bullets above.

5. Army Science Board, "1993 Summer Study: Final Report on Innovative Acquisition Strategies for the 90s," July 1994, Office of the Assistant Secretary of the Army (RDA).

This study makes five key recommendations. The first pertains to technology upgrading through use of horizontal technology integration (HTI) and vertical technology insertion (VTI) for a few key programs. This will help save constrained resources. The second pertains to digitization (and the need to establish priorities, codify operational requirements, and enforce standards to create an integrated system). The third is exploitation of simulation by better upgrades and new starts and by exploiting technology developed elsewhere and adapted to Army needs. The fourth is acquisition reform including use of the 2-step acquisition process for HTI and VTI. The fifth pertains to resourcing and the need to reduce acquisition and fixed costs in order to save modernization dollars. Figure C-2 is an overview of the evolving environment. These pressures will cause emphasis to be placed on upgrades in the future.

80s	NOW	FUTURE
Enough Resources for New Starts	Inadequate Acquisition Funding to Maintain New Start Approach	Technology Upgrades The Option for Continued Land Force Dominance, Requires Increased Investment.
5000 Series, Risk Averse, Gov't. Burden	Continued Reform and Revision	2-Step Development to Control Risk Early
Analog	Analog-Digital	Digital
Sequential Development Cycle, Exhaustive Test Environment	Proof of Concept Thru Simulation and Rapid Prototyping	Reduced Costs and Cycle Time Thru Wide-Spread Use of Simulation and Rapid Prototyping
Competition, Significant Overhead	Moving to Sole Source, Industry Reductions, Gov't. Streamlining	Sole Source, Stable of Qualified Vendors, Best Commercial Practice

RECOMMENDATIONS

•Technology Upgrades •Digitization •Simulation

•Acquisition System •Resources

Figure C-2: Evolving Acquisition Environment

A centerpiece of the study is a set of recommendations for projects which are suitable for HTI and VTI. The simplified 2-step model shown in figure C-3 is related to future application of technology integration. The point is that technical risk must be identified and mitigated early through open interaction and teamwork between Government and contractors.

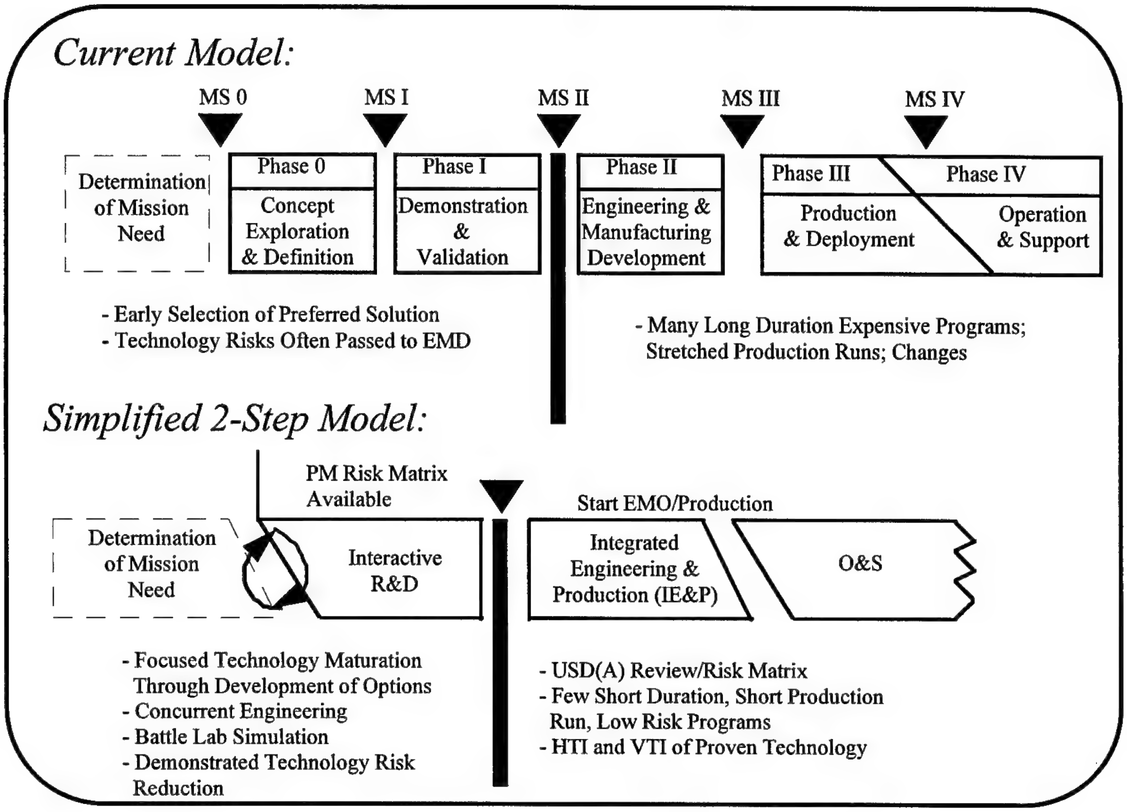

Figure C-3: A 2-Step Strategy for Technology Upgrades

Most important is an understanding that the single most frequent reason for program failure is the application of immature technology. This is entirely consistent with past studies, and in particular, with the 'Betti' acquisition study where an empirical data base of several hundred programs clearly identified technological risk as the single most important cause of program failure.

The 1993 Summer Study describes why the 2-step process is especially applicable to technology upgrades/HTI/VTI programs in terms of risk management. The 2-step process requires a cultural change in terms of trust and openness. Such a quality/cycle-time driven culture can help ensure successful programs.

The entire focus is proving, via demonstrations, that the employed technology will perform to the necessary levels by the time R&D (the first step) is finished. The Government-Industry team does this with the full knowledge that: at the end of step one, the technology performance must be met or the program will be terminated, and that moving to step 2 (actual integrated engineering and manufacturing development) with any technology risk still existing is unacceptable.

The study goes on to describe risk reduction and tools for managing risk. Simulation must be used early to reduce risk. It also discusses the need for cutting unneeded specifications and standards, better allocation mechanisms for funding, and use of the 2-step process. Major shifts in the culture and managerial paradigm are needed.

This study concurred with the 1991 Army Science Board study finding that the Army should exploit M&S technology that is developed elsewhere (i.e., take advantage of the commercial simulation revolution) and not invest except in areas of Army-unique needs. Much of the report pertained to improved training systems. The key point relating to M&S is to "develop and implement a common architecture and associated standards which support the interpretability and interconnectivity functions and dynamic interactions which affect the conduct and results of warfighting."

Much of the information from the 1993 Summer Study appears valid in terms of the discussions conducted during the course of the current study. Integration of technology, or gradual insertion of upgrades, is becoming increasingly prevalent for both existing and new programs. This goes hand-in-hand with increased attention to greater risk reduction, shorter cycle times and faster insertion of incremental improvements, and better integration of new capabilities across the force. The 2-step strategy more closely resembles evolving paradigms for both upgrades and new start programs as it requires closer team integration and reduction in barriers.

6. Acquisition Task Force on M&S, "Report Out of Acquisition Task Force on M&S," June 1994.

The Acquisition Task Force on M&S (ATFMS) interviewed many program managers and supporting personnel and functional experts and concluded that much system and program analysis is conducted in isolation, primarily due to lack of resources, infrastructure, and direction. However, the trend is toward greater integrated functional analysis. This generally encompasses "analysis that considers the impact of decisions, trade-offs, and risks both within and across acquisition functional disciplines." Another conclusion was that, due to budget reductions, program offices are making much greater use of M&S to reduce system development cost. Others factors causing increased use of M&S are the increased demands for program information, and increased capability and availability of M&S and related interconnectivity tools.

The ATFMS was established by Dr. Anita Jones to recommend actions to more effectively integrate the use of M&S throughout the acquisition process. The ATFMS found many examples of progress toward exploiting the potential of M&S. Programs specifically mentioned include the Air Force F-22, Army Comanche, and Navy Submarine Off-Board Mine Search System programs.

There were examples of M&S integration initiatives across functional areas. The DARPA DICE (DARPA Initiative on Concurrent Engineering) and MADE (Manufacturing Automation and Design Engineering) programs, using the Agile Manufacturing Information

Infrastructure, are attempting to integrate manufacturing enterprise disciplines. The DARPA program for Simulation Based Design is developing technology to support the transition of design efforts from the current use of drawings and mockups to use of virtual prototypes. Initial efforts in ship acquisition will later transition to interfacing this application with cost, manufacturing, and logistics M&S applications. The services and DoD agencies have developed joint standard applications and utilities, such as Joint M&S System (JMASS), Joint Simulation System (JSIMS), Distributed Interactive Simulation (DIS), and Defense Simulation Internet (DSI).

Other initiatives are integrating modeling vertically at specific centers and labs, for performance and effectiveness analysis, such as combining Extended Air Defense Simulation (EADSIM) with TAC BRAWLER to support Army and Air Force air defense and air operations centers and labs. Another example is the Army's intra- and inter-functional integration for the Advanced Warfighting Demonstrations and for various functions such as the Extended Air Defense and Missile Test Bed.

Promising cases of infrastructure investment and development, Service leadership in centralizing coordination and support for M&S, management innovation and development of educational programs and materials were cited. On the negative side, the ATFMS,

> discovered problems that limit the extent of M&S integration in a reformed acquisition process and impede the development of the core M&S technologies needed to facilitate such reform. The most important limitations are in the areas of cross-functional architectures, M&S support infrastructures, M&S management, M&S education and training, and M&S resourcing practices.

With regard to cross-functional architectures, the accelerating need for acquisition M&S caused the evolution of architectures "that are inconsistent with architectures evolving in the operations, training, and requirements analysis community." The other communities were building integrated M&S systems with common environments and objects. Organized effort is lacking at OSD level to create appropriate technical and managerial links between the battlefield and acquisition environments.

In terms of M&S support infrastructure, the absence of an overall architecture prevents the optimum return on investments. Most applications are unique to a specific program, developed to address program-unique problems, and are often contractor-unique solutions that the government doesn't own. When surveyed, program management personnel stated they wanted to make greater use of M&S but, "wondered about the nature of the architecture in which their simulations might be used and with which they should be compatible." In addition,

> Since PMs use system development funds to build and improve models, there is little incentive to use common standards or to adopt a common architecture except in instances where it is obvious resources can be saved for the program. Furthermore, there is little incentive to integrate models across functional areas because programs are

managed in narrow functional stovepipes at the center, major command, Services, and OSD level.

In the area of M&S resourcing practices, the report found that decentralized management resulted in inefficiencies. As discussed under infrastructure, functional stovepiping and the lack of incentives for integration results in models that are not properly shared and duplicative. Many respondents believed that "... one activity should be given responsibility for data maintenance and limited control of M&S development for specific environments," especially for configuration and data management functions. It appears that the USAF has best centralized configuration control and interface management control. With regard to M&S management, most respondents wanted to see an identifiable office or agency at OSD level with responsibility for a common acquisition M&S infrastructure.

> The ATFMS found that most users wanted the freedom to develop, improve, and integrate their models, but at the same time, they do not want to reproduce the same incompatibility problems present in their current set of legacy models. Many offices believe that an identifiable office at the OSD level needs to provide an overall vision and coordinate evolution of the M&S acquisition architecture.

The final area was the need for more education and training to inform prospective users of available M&S products. Potential users need to know what models are available to provide the right answers in the proper timeframe and at an acceptable price. Many of the proposed recommendations proved to be organizational rather than technical. Three principle recommendations were offered by the ATFMS to more effectively integrate the use of M&S throughout the acquisition process. The first involved the establishment of a JPO (joint program office) for M&S to help promote the establishment of the desired M&S infrastructure. Second, is that DDR&E establish an adequately resourced M&S staff in ODDR&E to provide the support needed for its M&S agenda. Finally, that DDR&E should sponsor experiments in M&S technologies in real programs so the Services can gain greater knowledge of their utility, benefits, costs and so forth.

With regard to the last recommendation, the report proposes criteria that can be used for selecting appropriate programs for M&S experimentation. Among the criteria are: phase of acquisition, status of requirement, level of funding, use of integrated decision team methods, program size, program experience in use of M&S, infrastructure for M&S, and applicability of results to other DoD acquisition programs.

A series of metrics are proposed for use in M&S experiments. Metrics were selected based on their ability to accurately measure the performance of the system under experiment, to provide proper focus for experiment managers, and to provide "...useful indicators for senior management to judge the overall performance of the experiment and its merits in other program environments..." The metrics, which relate to the present study, are summarized below.

COST SAVINGS:

- Extent to which estimated production unit cost can be reduced

- Extent to which system operation cost can be reduced
- Extent to which program can achieve savings in design and development tasks, relative to cost estimates based on current methods

TIME SAVINGS:

- Extent to which the number of iterative cycles has increased while reducing the total time spent on those cycles
- Reduction in time required to implement all supporting aspects of design (e.g., time required to change management documentation)
- Extent to which estimated time for the EMD phase is reduced

QUALITY IMPROVEMENTS:

- Quality of design reviews based on improved methods of visualizing data
- Quality of design information passed to and from industry

RISK MITIGATION:

- Extent to which risks associated with component design or selection can be mitigated
- Extent to which risks associated with use of individual processes and combinations of processes can be anticipated and appropriately compensated
- Extent to which M&S can be employed to make the T&E process more effective and efficient
- Extent to which 'system of systems' issues can be addressed during the conceptual design phase
- Extent to which M&S can be employed to identify and address critical support issues early in a program

The ATFMS report was published in June of 1994, and many of its recommendations have been adopted in some form. Nonetheless, many of the issues, terms of reference, and conclusions are still applicable for this study. The concerns and realities outlined in the study, such as declining budgets, increasing emphasis on acquisition reform, enabling technologies, and more dual-use applications, have caused DoD to transition to a more effective and efficient acquisition process. Some of the Service initiatives in response to the problems included the Army requirement that all ASARC programs have a Simulation Support Plan (SSP), the Navy N80 initiative to assess how M&S can lead to a better acquisition system, and Air Force regulations requiring manufacturing simulation plans. Many of these efforts focus on development of an integrated acquisition environment. The ATFMS summarized M&S needs using the standard categories for M&S functional areas as seen in figure C-4.

	T&E	Analysis	P&L	R&D	ETMO
1. Standards & Commonality	X	X	X	X	
2. Data Bases	X	X	X	X	X
3. Models and Simulations	X			X	X
4. Scenarios				X	X
5. Tools		X		X	X
6. Information Sharing	X			X	X
7. Interoperability	X		X		X
8. Networks	X				
9. VV&A	X	X		X	
10. Multi-level Security	X				X
11. M&S Policy Statements	X		X	X	
12. Education of Managers	X				X
13. Education of Practitioners	X				X
14. Environmental Representations	(X)	X		X	X
15. Behavioral Representations		X			X
16. M&S Development Environment	X	X		X	
17. New Models & Simulations		X	X		X

Figure C-4: Summary of M&S Needs

7. IDA Paper P-3062, "Review of Defense M&S Office Projects and Activities for FY 92 to 94," August 1995, Institute for Defense Analysis, M.H. Hammond, et. al.

This document reviews and provides summary information on 48 projects and 17 activities conducted from FY92 to FY94. The projects and activities are related to 1 of 9 technical areas (as might be expected, the areas receiving the most emphasis are architecture, information/databases, environmental representation, and interoperability with C3I systems) and 5 functional areas (ETMO received the greatest emphasis). Some of the projects of interest to this study, and which are discussed more fully later, include:

<u>FY92 Projects</u>: Joint M&S System (J-MASS) -- Department of the Air Force and J-MASS PO -- Architecture and methodology for integrating legacy data and tools, also for scenario development and for T&E.

Simulation Based Design for Military Systems Supportability and Human Factors -- DARPA and University of Iowa Center for Simulation and Design Optimization -- Extend SBD to ground vehicles to include maintainability aspects.

<u>FY93 Projects:</u> Integrated Radar and Infrared Analysis and Modeling (IRIAM) -- DoN and Naval Air Warfare Center -- Develop a prototype for improved analysis of multi-spectral measures and weapon systems data.

Prediction of Electronic Equipment Reliability Using Computer M&S -- DA and AMSAA --Develop improved models of electronic system reliability using physics-of-failure concepts.

FY94 Projects: AAAV: A Pilot M&S Program to Streamline T&E within the Acquisition Process -- DoN, PM for AAAV -- Analyze M&S/DIS resources that can be applied to reducing acquisition cost and increasing total system effectiveness.

The Integrated Priority List (IPL) process was used to select and prioritize the projects. Tables in the report list each project by priority, briefly describe it, and show which categories it impacts, either primarily or secondarily. Section 4 discusses how the projects and activities contributed in three areas of technological interest, including the area of advances in synthetic environments.

> These advances resulted from efforts to improve representation of the physical environment , to improve representation of weapons systems and military units, and to define, standardize, and enhance a number of simulation-related communication protocols.

Much of the report is devoted to discussion of standardization and enhancement of simulation protocols. The IDA Paper also describes the organization and initiatives of DMSO, including publications and regulations for which it is responsible, enhancement of simulation protocols, and efforts under the Defense M&S Initiative.

8. M&S Benefits Task Force, "Report Out to the M&S Benefits Task Force," December 5, 1995.

The goal of the M&S Benefits Task Force (MSBTF), authorized by the M&S Working Group under DMSO, was to capture documented reports of quantifiable M&S benefits. The MSBTF collected data using computerized requests for information and by other means. Data was collected in the application areas of acquisition, training, and analysis.

Very limited responses were received by the MSBTF from two data calls, which limited the ability of the task force to conduct a formal assessment. The report found that there is no formal reporting mechanism for reporting benefit information, nor is there a process for objectively assessing gathered information. The report concluded that analytic frameworks need to be developed and applied throughout DoD in order to understand the benefits of M&S.

In the area of target interaction, lethality, and vulnerability (TILV), a review of 21 case studies showed an average 30 to 1 ROI. The Army's Missile Command reported over $320M in cost avoidance and savings from 10 case studies. The Army's TECOM reported on 8 systems in which cost avoidance totaled about $80M using the Virtual Proving Ground concept. Finally, the Apache Longbow program conducted two similar test events, one using extensive simulation and the other using physical equipment and personnel. "The simulation-supported event

executed twice as many trials, with fewer personnel, in less time, at lower risk to personnel, for $700,000 versus $4 million."

Two members of the task force prepared analyses to provide measures of effectiveness and methods of analysis (Appendices A and B of the cited report). Appendix A describes possible reasons why the value of using M&S is difficult to quantify: lack of accepted metrics, difficulty in obtaining supporting data, and difficulty in identifying a valid baseline from which to measure increases in value. M&S capabilities are divided into the two broad areas of technical and functional. The technical area deals with mechanisms that make the M&S application work. The functional area considers how M&S applications will be used. Tables C-2 and C-3 provide a sample of important area topics and proposed quantitative and qualitative metrics or MOEs for each.

Appendix B compares alternative methods of calculating cost effectiveness using three case studies pertaining to M&S use. Analyses results are as follows:

> There are four basic categories of effectiveness measures obtained from applying M&S -- doing it better, doing it faster, doing it cheaper, and doing it at all. However, the metrics are often hard to measure especially in terms of dollars. What value is ascribed to a safer or better process? For example, what is the value of avoiding a disaster, near miss, or a high-risk test? What is the value of an event or a series of thousands of discrete events that would not be possible without use of a simulation? What is the value when a faster and more cost efficient solution is found by using M&S?

TABLE C-2: Technical Areas

- Architecture: the high-level system and software design of the M&S tool. A quantitative metric is the amount or *percent of legacy migration* to the new system.

- Environmental representation: how well the real world is portrayed in the synthetic environment. A candidate quantitative metric is *stimulation*, or the number of environmental effects that the M&S application can portray. A possible qualitative metric is *immersion*, or how real the environment feels to a human.

- Information/database: methods for M&S tools to store or access information or for data modeling. A quantitative metric is *level of effort required for collaboration and reuse.*

- Interoperability: how various M&S tools interface and operate together. A qualitative metric proposed for this area is called *level playing field.* This embodies the idea of a neutral evaluation tool that treats all Service roles and missions fairly.

- Networking: how data is shared between dispersed and remote M&S tools. Possible quantitative metrics are *cost per megabit per second* and *latency*. A possible qualitative metric is *immersion*, the quality of realistic sensory stimulation.

- VV&A: the process of fully approving M&S tools. A quantitative metric is *cost avoidance* for VV&A procedures that enhance reuse. A proposed qualitative metric is *enhanced decision support*, such that the VV&A process results are 'more valid' and lead to better quality decisions.

- Instrumentation: the details of the infrastructure that help send state variables between M&S tools. A proposed quantitative metric is *risk reduction*, in that the instrumentation helps in position reporting and similar actions that can help reduce risk. A qualitative metric is *merger of C4I with M&S.* For a number of reasons (cost, simplicity, integration), it is desirable for these two disciplines to merge.

TABLE C-3: Functional Areas

- Analysis: use of M&S to conduct experiments to extract useful data. A candidate quantitative metric is *net utility* defined as how the M&S tools allow an analyst to better understand a process or to gain useful data. A qualitative metric is *data quality* or the level to which the obtained data is useful for analysis.

- Acquisition (R&D): M&S used to enhance concept evaluation, prototyping, and so forth. Possible quantitative metrics are *cost savings*, and *number of options considered.* Possible qualitative metrics are *brainstorming* and *unique capability.* The first pertains to the ability of M&S to explore a wider array of options before deciding on a solution or approach. The latter applies to actions that are difficult to do in real life (i.e., without M&S).

- Acquisition (T&E): conducting developmental and operational testing using M&S. Use of *cost avoidance* as a quantitative metric is well supported by a number of studies. A number of qualitative metrics are proposed including *test planning*, *development of MOPs* and *development of MOEs.* These qualitative metrics allow users to describe how well M&S tools assist with the stated tasks.

- Acquisition (P&L): use of M&S for functions such as manufacturing, process analysis, and support planning. Possible quantitative metrics are *cost savings* resulting from simulation that assists in problem identification/correction, and *number of options considered*, in terms of options using production equipment and constraints.

Table C-4 provides useful guidance on how to determine the value of M&S tools as they are used for various aspects of the acquisition process.

TABLE C-4: Value of M&S Tools for Various Parts of the Acquisition Process

	MEASURE OF EFFECTIVENESS (MOE)	DETERMINATION OF MOE
RDT&E AND ANALYSIS:		
FASTER	Better adherence to schedule	Review daily expenditures
	Use of virtual prototyping	Look at turn-around time from physical models
BETTER	Value of more detailed analysis	Reduced number of design, S/W, planning changes
	Value added of considering more alternatives	Can review P3I and other alternatives
	Value added of making better decisions	Reduced false starts/backup plans for risk mitigation
CHEAPER	Cost savings of using new methods	Better review of current and projected cost; "what ifs"
AT ALL	Value added of "executable" requirements	Costs of erroneous requirements: redesigns, ambiguity
RDT&E, DESIGN PHASE:		
FASTER	Reduction of design iterations	Compare to similar effort
	Automatic design documentation	Compare to manual methods
BETTER	Incorporate maintenance, logistics, and production considerations	Estimates of reduced LCC from what simulations reveal
CHEAPER	Use of virtual prototypes	Cost of physical models
AT ALL	Evaluation of designs under more situations	Estimated costs of design failure under such situations
TEST AND EVALUATION:		
FASTER	Better adherence to schedule	Daily cost of ranges, program slips
	Better use of flight test time	Percent of test time wasted
BETTER	Value added of "monte carloing" test conditions	Percent of ops requirements not physically tested, but inferred from testing
	Value added of rehearsing test	Percent of tests wasted
	Earlier identification of problems	Look at cost/spending curve by phase of project; look at cost of ECPs by phase
CHEAPER	Use of virtual prototyping	Cost of physical models
AT ALL	Evaluations of designs under more situations	Estimated costs of design failure under such situations